

Research on Financing Efficiency of Intelligent Manufacturing Enterprises in China

--Empirical analysis based on DEA-Malmquist modeling

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Abstract. Smart manufacturing is leading the way in the development of manufacturing quality in China. Based on the DEA-Malmquist model, this paper analyses the financing efficiency of 88 listed smart manufacturing enterprises in China from 2017 to 2021. The results of DEA static analysis show that: in terms of industry types, the comprehensive technical efficiency of the light textile industry is the highest, the resource processing industry has serious internal polarisation, and the machinery and electronic manufacturing industries are mainly affected by pure technical efficiency. Malmquist dynamic analysis shows that: the average total factor productivity index of listed enterprises in intelligent manufacturing is 0.9835, of which, the change value of pure technical efficiency leads to the annual average financing efficiency. The value of efficiency change leads to an average annual decline of 1.65% in financing efficiency. Therefore, the financing efficiency of Chinese intelligent manufacturing enterprises can be improved from the dimensions of improving the bond financing support system and constructing advanced manufacturing innovation system.

Keywords: Smart Manufacturing Listed Companies, Financing Efficiency, DEA-Malmquist model

1. Introduction

The development of smart manufacturing companies is highly dependent on R&D investment and technological innovation. Therefore, efficient financing can help enterprises obtain funds at high speed and low cost, promote the sustainable development of R&D and production activities, and provide protection for subsequent investment and operation. Nowadays, Chinese intelligent manufacturing enterprises face many problems, such as the mismatch between diversified capital demand and financing channels, and the mismatch between long-term capital demand and financing period. Therefore, this paper uses the DEA-Malmquist model to evaluate the financing efficiency of smart manufacturing companies during the period of 2017-2021 by looking at three dimensions: the nature of the company, the region it is located in and the industry.

Intelligent manufacturing, as a development path for the modernisation and transformation of China's manufacturing industry, urgently requires the efficient raising and use of capital. Currently, financing efficiency evaluation methods and financing efficiency evaluation index system mainly constitute the study of financing efficiency.

1.1. Construction of Financing Efficiency Evaluation Indicator System

The two parts of financing input and financing output constitute the enterprise financing efficiency evaluation index system. Financing input refers to the scale and structure of enterprise financing; financing output refers to the role of the incorporated funds on enterprise development. Yao Dingjun et al. (2023)[1] selected paid-in capital, total liabilities, retained earnings and R&D inputs as input indicators, and main business income and net profit as output indicators from the characteristics of financing channels and revenue characteristics of unlisted technology SMEs. Xiao Yiping et al. (2022) [2] studied the financing efficiency of the top 100 intelligent manufacturing enterprises by taking the growth rate of total assets, the growth rate of financial expenses, and the asset-liability ratio as input indicators, and the return on net assets and the return on total assets as output indicators.

1.2. Methods for evaluating the efficiency of enterprise financing

Domestic methods about evaluating the efficiency of enterprise financing mainly include fuzzy evaluation method, entropy value method and data envelopment analysis method.

(1) Fuzzy evaluation method. Deng Hongzheng and Zhou Changxin (2003) [3] used the fuzzy system method to conduct a comprehensive evaluation of the financing efficiency problems of Chinese SMEs and concluded that enterprise funds should be financed strictly in the order of free financing.

(2) Entropy value method. Guo Ping (2012) [4] utilized the entropy value method to conduct an empirical study on 36 enterprises listed on China's Growth Enterprise Market (GEM), and concluded that the financing efficiency of China's GEM-listed companies is not high, and that China must increase its support for listed companies.

(3) Data Envelopment Analysis (DEA) method. This method is commonly used to study the efficiency of corporate financing. Liu Lichang et al. (2004) [5] for the first time used the DEA model in the analysis of corporate financing efficiency, in which 47 listed companies were used as the object of research, and concluded that the efficiency of equity financing of Chinese listed companies is generally inefficient.

Summarizing the existing evaluation methods, it is found that the fuzzy comprehensive evaluation focuses on quantifying and synthesizing the fuzzy information of various financing efficiency evaluation indexes, but it is difficult to deal with the evaluation indexes with interdependent relationships; the entropy method determines the weights based on the size of the information provided by the observed values of the various indexes of enterprise financing efficiency, but the conclusions drawn by this method have a large error; and the two-phase EDA model doesn't reflect the issue of whether the efficiency of the research object. The DEA-Malmquist index model is based on both dynamic and static aspects, and the measured efficiency values can more objectively reflect the internal management level of the evaluation object. Therefore, it is necessary to use the DEA-Malmquist model to evaluate the financing efficiency of intelligent manufacturing enterprises during the period of 2017-2021 from the three dimensions of the nature of the enterprise, the region and the industry.

1.3. Data Envelopment Analysis

The DEA models are mainly used to calculate the efficiency of break-in outputs, where the DEA-CCR model calculates the composite efficiency by disregarding changes in returns to scale. The DEA-BCC model takes into account changes in returns to scale, removes the assumption of fixed returns to scale, and takes into account the effect of returns to scale in calculating the value of the relative efficiencies to arrive at the purely technical efficiencies. Both DEA models are used to measure static efficiency. Therefore, this paper uses the BCC model on the basis of input orientation to calculate the financing integrated efficiency (TE), pure technical efficiency (PTE), and scale efficiency (SE) of 88 smart manufacturing enterprises in China, as shown in Equation 1: [9]:

$$\begin{aligned} & \min \theta \\ \text{s. t. } & \begin{cases} \sum_{j=1}^n \lambda_j x_{ij} \leq \theta x_{kj}, i = 1, 2, 3, \dots, m \\ \sum_{j=1}^n \lambda_j y_{hj} \geq y_{jk}, h = 1, 2, 3, \dots, s \\ \sum \lambda_j = 1, j = 1, 2, 3, \dots, n \end{cases} \end{aligned} \quad (1)$$

The relationship between combined efficiency, technical efficiency and scale efficiency is shown in equation 2.

$$\theta_{TE} = \theta_{PTE} \times \theta_{SE} \quad (2)$$

If $\theta_{TE} = 1$, it means that the decision-making unit is in an effective state when the technology level is stable; if $\theta_{PTE} = 1$, it means that the decision-making unit resources to achieve a reasonable allocation, to achieve effective technical efficiency; if θ_{PTE} is smaller, it means that the decision-making unit more need to upgrade technology, improve resource allocation; If $\theta_{SE} = 1$, it means that the decision-making unit is in an effective state in terms of scale.

1.4. Malmquist Index

Based on the Malmquist index, this paper aims to study the dynamic change characteristics of financing efficiency of 88 smart manufacturing enterprises in China, while decomposing the Malmquist index into technological change and technological efficiency change, the Malmquist index measures the DEA model from period t to period $t+1$ of Equation 3 [6]

$$M_{i,t+1} = \sqrt{\frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^{t+1}(x^t, y^t)} \times \frac{D^t(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)}} \quad (3)$$

where $M_{i,t+1}$ denotes the productivity index. In addition, the Malmquist index measurement formula can be obtained from the four data of comprehensive efficiency change index, technical efficiency change index, scale efficiency change index, and technological progress index, which are expressed as follows: comprehensive efficiency change index = technical efficiency change index * scale efficiency change index, and total factor productivity index = comprehensive scale change index * technological progress index.

1.5. Data sources

This paper takes the intelligent manufacturing demonstration enterprises announced by China's Ministry of Industry and Information Technology in 2017-2021 as the research object, and selects A-share listed enterprises as samples from them, according to the availability and credibility of the data, sieves out some of the enterprises with missing data, and ultimately retains 88 valid enterprises, and the main data comes from the database of GuotaiAn.

1.6. Selection of indicators

The gearing ratio, financial expense ratio, and equity ratio are selected as input indicators, and the return on net assets, total asset turnover ratio, and operating income growth rate are selected as output indicators, as shown in Table 1.

Tables 1. Financing Efficiency Measurement Indicator System for Smart Manufacturing Enterprises

Typology	Serial number	Indicator name	Definition of indicators
Inputs Indicators	X_1	Gearing	Total liabilities at end of period/Total assets at end of period
	X_2	Financial Cost Ratio	Finance costs/Gross operating income
	X_3	Ownership Ratio	Total liabilities/Shareholders' equity
Outputs Indicators	Y_1	Return On Net Assets	Net profit/shareholders' equity balance
	Y_2	Total asset turnover	Sales revenue/Average total assets
	Y_3	Revenue growth rate	Growth in operating income/total operating income of the previous year

2. Analysis of empirical results on financing efficiency of intelligent manufacturing enterprises

2.1. Comparison of Financing Efficiency in Intelligent Manufacturing Industry

2.1.1 Business type perspective

Tables 2. Results of DEA Analysis of Financing Efficiency in Different Industries of Smart Manufacturing

Particular year	Resource processing industry			Mechanical and electronic manufacturing			Light textile industry		
	Crste	Vrste	Scale	Crste	Vrste	Scale	Crste	Vrste	Scale
2017	0.597	0.617	0.972	0.596	0.612	0.973	0.659	0.699	0.983
2018	0.509	0.576	0.925	0.486	0.495	0.991	0.553	0.560	0.991
2019	0.545	0.597	0.929	0.517	0.578	0.917	0.566	0.613	0.929
2020	0.591	0.620	0.949	0.518	0.601	0.892	0.586	0.671	0.904
2021	0.611	0.684	0.910	0.553	0.588	0.946	0.608	0.651	0.939
Average value	0.571	0.619	0.937	0.534	0.575	0.944	0.594	0.639	0.949

As shown in Table 2, in terms of comprehensive technical efficiency, it is characterised by "machinery and electronic manufacturing industry < resource processing industry < light textile industry". On the whole, their comprehensive technical efficiency is a certain gap from the ideal state. Therefore, it is necessary to reduce the waste of funds and improve the efficiency of the use of funds in the process of development of intelligent manufacturing enterprises.

Construct a decomposition diagram with pure technical efficiency as the X-axis and scale efficiency as the Y-axis, and divide it into "double-high", "high-low", "low-high", "double-low" and "low-high", respectively, with 0.8 and 0.95 as the boundaries. "double-low" four types of regions.

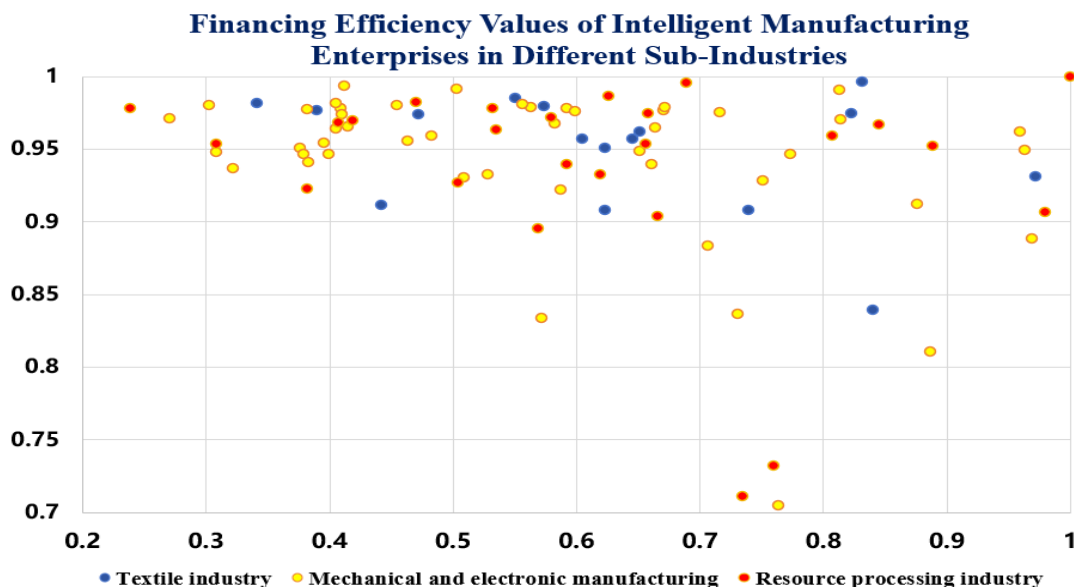


Figure 1. Decomposition of Financing Efficiency of Intelligent Manufacturing Enterprises in Different Sub-Industries

As shown in Figure 1, the double-high type: two enterprises in the textile industry accounted for 12.5 per cent of the total number of enterprises in the textile industry; four enterprises in the machinery and electronic manufacturing industry accounted for 8.51 per cent of the total number of enterprises in the machinery and electronic manufacturing industry; and four enterprises in the resource processing industry accounted for 16 per cent of the total number of enterprises in the

resource price industry. Therefore, enterprises in the textile industry and the machinery and electronic manufacturing industry can appropriately improve the level of management and technology to improve the comprehensive technical efficiency.

High and low type: the textile industry contains 2 enterprises, accounting for 12.5% of the total number of enterprises in the textile industry; machinery, electronic manufacturing industry contains 3 enterprises, accounting for 6.38% of the total number of enterprises in the machinery, electronic manufacturing industry; resource processing industry contains 1 enterprise, accounting for 4% of the total number of enterprises in the resource processing industry. Among them, the textile industry category has the highest proportion of enterprises, such enterprises in the development process should focus on improving the production scale of the enterprise, expanding capital, technology channels, and improve the efficiency of the scale.

Low-high type: the textile industry contains 9 enterprises, accounting for 56.25% of the total number of enterprises in the textile industry; machinery, electronics manufacturing industry contains 26 enterprises, accounting for 55.31% of the total number of enterprises in the machinery, electronics manufacturing industry; resource processing industry contains 12 enterprises, accounting for 48% of the total number of enterprises in the resource processing industry. Among them, the proportion of textile industry enterprises and resource processing enterprises are more than 50%, which should focus on improving the level of scientific and technological management, and technological innovation.

Double-low type: the textile industry contains 3 enterprises, accounting for 18.75% of the total number of enterprises in the textile industry; machinery, electronic manufacturing industry contains 14 enterprises, accounting for 29.79% of the total number of enterprises in the machinery, electronic manufacturing industry; resource processing industry contains 8 enterprises, accounting for 32% of the total number of enterprises in the machinery, electronic manufacturing industry. The proportion of enterprises in the machinery, electronics manufacturing industry and resource processing industry is large, so these two types of enterprises should optimise the allocation of resources and optimise the technical level, management level and other aspects.

2.1.2 Geographic perspective of the enterprise

Tables 3. Results of DEA Analysis of Financing Efficiency of Intelligent Manufacturing Enterprises in Different Regions of China

Particular year	Eastern Region			Central Region			Western Region			North-eastern Region		
	Crste	Vrste	Scale	Crste	Vrste	Scale	Crste	Vrste	Scale	Crste	Vrste	Scale
2017	0.618	0.633	0.977	0.593	0.593	0.979	0.563	0.583	0.964	0.740	0.763	0.967
2018	0.530	0.557	0.969	0.455	0.492	0.962	0.483	0.491	0.991	0.462	0.469	0.986
2019	0.544	0.577	0.943	0.508	0.593	0.894	0.540	0.617	0.901	0.495	0.633	0.851
2020	0.547	0.601	0.926	0.608	0.683	0.903	0.517	0.591	0.900	0.501	0.683	0.800
2021	0.573	0.626	0.931	0.599	0.629	0.954	0.601	0.634	0.947	0.535	0.610	0.881
Average value	0.562	0.599	0.949	0.553	0.598	0.938	0.541	0.585	0.941	0.547	0.632	0.897

As shown in table 3, from the perspective of comprehensive technical efficiency, the comprehensive technical level of China's four major regions is characterised by "East > Central > Northeast > West", but there is still plenty of room for the comprehensive technical efficiency of the four types to continue to improve. From an overall perspective, the scale efficiency of intelligent manufacturing enterprises in these four regions is much larger than the pure technical efficiency, indicating that the local government needs to introduce high-tech talents, improve R&D capabilities, and improve pure technical efficiency in the process of promoting enterprise development.

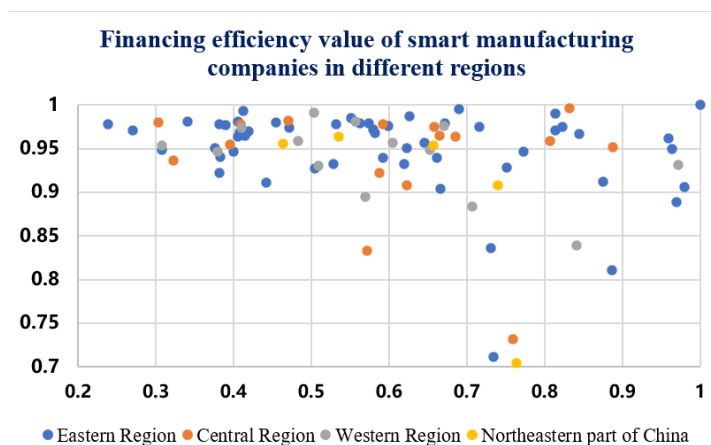


Figure 2. Decomposition of Financing Efficiency of Intelligent Manufacturing Enterprises in Different Regions of China

As shown in Figure 2, the double-high type: the eastern region includes seven enterprises, accounting for 13.20 % all enterprises in the eastern region; the central region includes three enterprises, accounting for 18.75 % all enterprises in the central region. In comparison, the combined technology level of enterprises in the western and northeastern regions is low, so local governments should guide companies to upgrade their technology level and optimise the financing environment in the region.

High-low type: the eastern region includes 4 enterprises, accounting for 7.54% of all enterprises in the eastern region; the western region includes 2 enterprises, accounting for 14.29% of all enterprises in the western region. The relative share of the western region is high, so the local government should enhance financial support to improve the efficiency of enterprise scale.

Low-high: the eastern region includes 30 enterprises, accounting for 55.6% of all enterprises in the eastern region; the central low region includes 8 enterprises, accounting for 50% of all enterprises in the central region; the western region includes 9 enterprises, accounting for 64.29% of all enterprises in the western region; the northeastern region includes 3 enterprises, accounting for 60% of all enterprises in the northeastern region. Taken together, smart manufacturing enterprises in all regions are lacking in pure technical efficiency, so governments around the world should increase support for technological innovation and R&D and assist enterprises in upgrading their management skills.

Double Low: The eastern region includes 13 enterprises, accounting for 24.53% of all enterprises in the Eastern region; the Central region includes 5 enterprises, accounting for 31.25% of all enterprises in the Central region; the Western region includes 3 enterprises, accounting for 21.43% of all enterprises in the Western region; and the Northeastern region includes 2 enterprises, accounting for 40% of all enterprises in the Northeastern region. Among them, the northeast region accounts for the largest proportion. Therefore, the local government should enhance the overall quality of local enterprises by strengthening policy support, promoting enterprise cooperation and other dimensions.

2.1.3 Enterprise ownership perspective

Tables 4. Results of DEA Analysis of Financing Efficiency of Intelligent Manufacturing Enterprises under Different Ownership Systems

Particular year	State Enterprise			Non-state Enterprise		
	Crste	Vrste	Scale	Crste	Vrste	Scale
2017	0.602	0.628	0.961	0.615	0.623	0.985
2018	0.517	0.548	0.968	0.496	0.516	0.975
2019	0.561	0.606	0.937	0.509	0.571	0.914
2020	0.570	0.620	0.929	0.536	0.619	0.897
2021	0.625	0.660	0.953	0.546	0.601	0.921
Average value	0.575	0.612	0.950	0.540	0.586	0.938

As shown in Table 4, as far as comprehensive technical efficiency is concerned, the average value of comprehensive technical efficiency of state-owned enterprises is 0.575, and that of non-state-owned enterprises is 0.5404, and the value of comprehensive efficiency of state-owned enterprises in intelligent manufacturing is higher than that of non-state-owned enterprises, which is specifically shown in the development of both pure technical efficiency and scale efficiency. Overall, both types of nature of enterprises have low pure technical efficiency, so both need to improve the efficiency of the use of existing technology, equipment and human resources in the process of development.

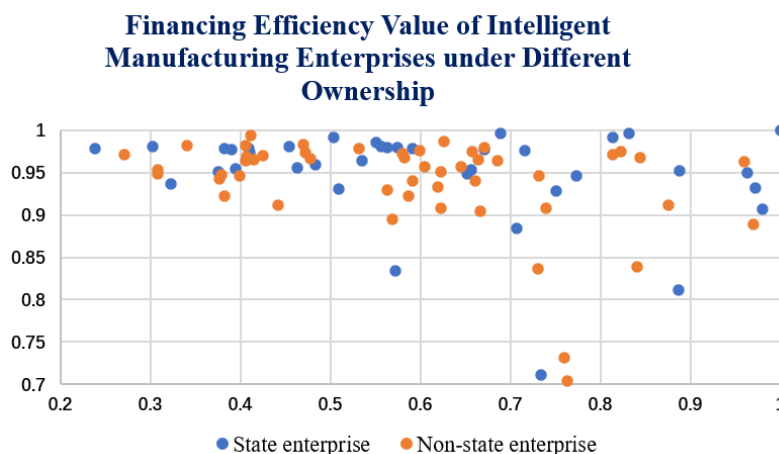


Figure 3. Decomposition of Financing Efficiency of Intelligent Manufacturing Enterprises under Different Ownership in China

As shown in Figure 3, the double-high type: the state-owned system includes five enterprises, accounting for 13.16% of all state-owned enterprises; the non-state-owned system includes four companies, accounting for 8% of all non-state-owned enterprises. Therefore, non-state-owned enterprises should focus on the further improvement of comprehensive technical efficiency.

High-low type: the state-owned system includes three enterprises, accounting for 7.89 % all state-owned enterprises; the non-state-owned system includes three enterprises, accounting for 6 per cent of all non-state-owned enterprises. From this ratio, it can be seen that the number of purely technically efficient enterprises with low scale efficiency is higher in the State-owned system, so it is necessary to focus on improving production capacity and resource allocation efficiency.

Low-high type: State-owned system includes 22 enterprises, accounting for 57.89% of all state-owned enterprises; non-state-owned system includes 25 companies, accounting for 50% of all non-state-owned enterprises. So in the process of development, we should focus on improving research and development capabilities, launching new products and processes, and improving the efficiency of pure technology.

Double-low type: State-owned system includes 8 enterprises, accounting for 21.05% of all state-owned enterprises; non-state-owned system includes 18 companies, accounting for 36% of all non-state-owned enterprises. The proportion of non-state-owned enterprises in this type is relatively high, so in the process of development, it is necessary to focus on improving production capacity and optimizing resource allocation, as well as improving research and development capabilities and production process efficiency.

2.2. Analysis of All Factor Production Factors for Listed Smart Manufacturing Companies

2.2.1 Overall Total Factor Productivity and Decomposition of Listed Smart Manufacturing Companies

According to Figure 4, From 2017-2021, the average total factor productivity index of listed smart manufacturing enterprises is 0.9835 , indicating that the financing efficiency of listed smart manufacturing enterprises in China declines by an average of 1.65% per annum , and overall, total

factor productivity shows a downward trend in 2017-2018 , after rebounding in in 2018-2019 2019-2020 declines again, and in 2020-2021 rising slowly.

As shown in table 5, the trend in the value of changes in pure technical efficiency is decreasing and then increasing at an average annual rate of 0.1%, with a peak in 2018-2019, indicating that the intelligent manufacturing enterprises realized technological innovation or improvement during this period and efficiently utilized the existing technology and resources; at the same time, the change value of pure technical efficiency is greater than 1 in multiple periods and is consistent with the trend of changes in the financing efficiency, which indicates that the pure technical efficiency improvement of intelligent manufacturing enterprises plays a greater role in the financing efficiency of intelligent manufacturing enterprises. Meanwhile, the change value of pure technical efficiency is greater than 1 in several periods and consistent with the change trend of financing efficiency, indicating that the improvement of technical efficiency of intelligent manufacturing enterprises has a greater role in financing efficiency of intelligent manufacturing enterprises. The change values of technical efficiency, technical progress index and scale efficiency are 0.995, 0.991 and 0.989 respectively, indicating that the financing efficiency of enterprises has maintained a high level in both technical and scale efficiency, although it has slightly decreased compared with the base period.

Tables 5. Financing Efficiency of Smart Manufacturing Firms TFP and Its Decomposition, 2017-2021

Year	Effch	Techch	Pech	Sech	Tfpch
2017-2018	0.809	1.022	0.816	0.990	0.826
2018-2019	1.066	0.982	1.129	0.945	1.047
2019-2020	1.039	0.950	1.048	0.991	0.988
2020-2021	1.064	1.009	1.033	1.030	1.073
Average value	0.995	0.991	1.001	0.989	0.9835

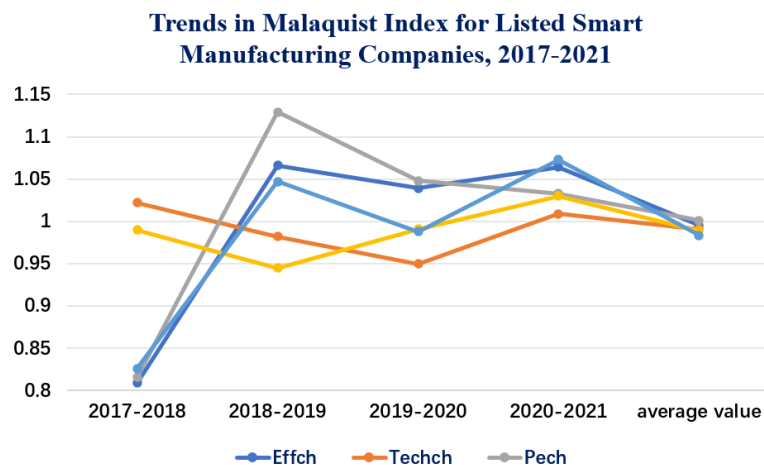


Figure 4. Total Factor Productivity and Decomposition Indicators for Smart Manufacturing Companies, 2017-2021

3. Conclusions and recommendations

3.1. Conclusion

Static analysis perspectives: first, in terms of industry types, the light textile industry has the highest comprehensive technical efficiency of 0.949, while there are many enterprises with both high and low scale efficiency and pure technical efficiency in the resource processing industry, and there is a serious polarization within the industry, and the machinery and electronic manufacturing industries are mainly affected by pure technical efficiency, and scale efficiency dominates the financing efficiency of the intelligent manufacturing industry; second, as far as the geographical

location is concerned, the financing efficiency of China's intelligent manufacturers mainly shows the trend of "east high, west low", and the overall pure technical efficiency is low. Secondly, in terms of the geographical location of the enterprise, China's intelligent manufacturing enterprise financing efficiency mainly presents the development trend of "east high and west low", the overall pure technical efficiency is low, of which, the eastern region and the northeastern region respectively in the scale efficiency and pure technical efficiency has a significant advantage, the central and western regions need to be strengthened in the two aspects; Finally, as far as business ownership is concerned, the financing efficiency of state-owned firms compares favorably with that of non-state-owned firms, and performs better in terms of both pure technical efficiency and scale efficiency.

Dynamic analysis perspective: in 2017-2021, the average total factor productivity index of smart manufacturing listed enterprises is 0.9835, and the average annual decline in financing efficiency is 1.65%, of which, the development trend is weaker in 2017-2018 and 2019-2020, which is a period of declining waves, and the development trend is better in 2018-2019 and 2020-2021, which is a period of ascending waves, in which the value of pure technical efficiency change, technical progress index, and scale efficiency change that plays a role of facilitating role is the value of pure technical efficiency changes, while those playing a constraining role are the value of technical efficiency changes, technical progress index, and scale efficiency changes.

3.2. Recommendations

3.2.1 Reducing financing costs

Reducing financing costs can effectively reduce the financial burden on enterprises and promote the release of more funds for production, research and development. At present, the government and financial institutions can reduce the financing cost of intelligent manufacturing enterprises.

The government can strengthen the policy support for intelligent manufacturing enterprises, the development of relevant tax reduction policies; improve the bond financing support system, through the development of debt financing policy, the establishment of the bond market system and other initiatives, to provide enterprises with a stable and standardised financing environment. In addition, the government also needs to strengthen cooperation, cooperation with banks and other financial institutions, integration of policy guarantee institutions, the creation of a multi-layer financing guarantee system, and on this basis, actively explore a variety of financing methods in favour of intelligent manufacturing enterprises, to broaden the channels of equity financing. As for financial institutions, financial institutions should rely on digital technology to accurately identify and assess risks and broaden the financing surface of intelligent manufacturing enterprises. [7]

3.2.2 Increase investment in scientific research

The government should guide the whole society to build an advanced manufacturing innovation system, take the initiative to adopt a corporate cooperation model led by the government, led by enterprises, and supported by universities and scientific research institutions as well as other non-profit organisations, so as to create a highland of advanced manufacturing innovation. Enterprises should take the initiative to formulate research investment plans to ensure the continuity and stability of research investment, in addition to timely adjustment of research direction and strategy to ensure the foresight of research investment. [8]

3.2.3 Strengthening of the talent pipeline

Talent plays an important role in improving the efficiency of pure technology in smart manufacturing companies. In terms of internal talent training, in addition to establishing a perfect training system, enterprises should also strengthen the ability of employees in intelligent manufacturing, finance and accounting, in addition, with the help of manufacturing industry-university-research cooperation centers and other channels, the establishment of a talent introduction mechanism for enterprises to cultivate and introduce a number of manufacturing talents. [9]

3.2.4 Improvement of enterprise management

The Company should strengthen its ability in the level of financial management, improve the efficiency of capital use, reduce financial costs and thus increase the profitability of the enterprise, and at the same time further establish an early warning mechanism for financing risks, even if it detects and analyzes the financing risks, to effectively reduce the risks of financing and improve the efficiency of financing. [10]

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