Analysis on Total Factor Productivity and Differences of Industrial Internet Concept Companies

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Based on the Malmquist-DEA model and the DEA-BCC model, using the data of 53 industrial Internet-listed companies, the total factor productivity (TFP), technological progress (TC), and technical efficiency changes of the industrial Internet industry were measured from static and dynamic perspectives (EC), and used the coefficient of variation to further analyze the variance variables that measure the differences between enterprises in various subsectors in the industrial Internet industry. The study pointed out that the overall productivity level of the industrial Internet industry in 2015 to 2019 was low, and the fluctuation range was large, especially the sharp drop in productivity in 2016 to 2017, which had a serious impact on the entire industry. At the same time, changes in technical efficiency are the main reason for the decline in total factor productivity after 2015. Among various industries, the Malmquist indices of manufacturing and information transmission, software, and information technology services are all less than 1, and there is little difference in production efficiency and changes between the two. This study provides a reference for the productivity measurement of the industrial Internet industry based on the Malmquist-DEA model and provides practical inspiration for future management activities.

1. Introduction

As the in-depth integration of the gradually developed Internet and the currently developed industrial system, the Industrial Internet has promoted the expansion of the Internet from the consumption field to the production field and the deep integration of the virtual economy and the real economy. It is a redefinition of the manufacturing industry. This concept was first proposed by General Electric Company of the United States, and then five companies including General Electric and Intel quickly promoted this concept [1]. Countries are deploying the industrial Internet industry. Based on its advantages in machinery and industrial management software, the German government has launched the “Industry 4.0” national plan; the French government has launched “New Industrial France” to lay out digital manufacturing and intelligent manufacturing, and drive changes in its business model. In addition, the British government proposed the “Made in Britain 2050,” which also represents the current level of attention that countries attach to the industrial Internet industry. In China, more and more listed companies are actively developing and using industrial Internet platforms. These companies are called “industrial Internet concept stocks” listed companies. In recent years, the contribution of the Industrial Internet to China’s economic development has shown an increasing trend. Data show that the scale of economic impact driven by the Industrial Internet in 2020 is about 2.5 trillion yuan, and its contribution to China’s GDP growth in the future will exceed 11%. As a revolution of the Internet in the industrial field, the development of the Industrial Internet is the key support for enabling the transformation and innovation of the manufacturing industry, as well as an important starting point for promoting the high-quality development of the manufacturing industry. In 2019, the Industrial Internet Industry Alliance released the second edition of the industrial Internet architecture based on technologies such as security; in January 2021, the “Industrial Internet Innovation and Development Action Plan (2021–2023)” issued by the Ministry of Industry and Information Technology pointed...
out that industrial Internet technology should be used to promote China’s industrialization and informatization, which are more widely and deeply integrated and developed. The 2021 “Government Work Report” emphasizes the importance of innovation to improve the quality of real economic development and develop new kinetic energy.

In fact, China’s industrial Internet industry still has many problems, such as its own low level of core technology, insufficient innovation capability, imperfect system, and low degree of information security. The number of industrial Internet-listed companies in China is relatively small, except for the leading companies, which are generally small in scale. At the same time, the increasing complexity of domestic and foreign economic and political environment also puts forward higher requirements for the independent innovation ability and sustainable development ability of Chinese enterprises. Therefore, improving the total factor productivity of industrial Internet industry and developing China’s industrial Internet industry have become the key to resisting the uncertain factors and promoting the construction of new infrastructure nationwide.

Since the concept of industrial Internet was put forward, scholars in many disciplines at home and abroad have studied the optimization and application of industrial Internet platforms. Posada et al. [2], Yin et al. [3], Kaur et al. [4], and Aazam et al. [5], respectively, studied the methods of innovating industrial Internet platforms from the aspects of visual computing, edge computing, data security, fog manufacturing, and so on. In the specific application of industrial Internet and its impact on industry and economic development, Burmeister et al. [6] pointed out the future practice of industrial Internet application and the key capabilities needed by constructing I40 business model and combining the characteristics of business model; Li et al. [7] showed the 5C architecture of the industrial Internet and outlines the current status of industrial Internet applications in various industries; Chen et al. [8] used the Porter Diamond Model to study several comprehensive indicators in China over the past 15 years and found that technological innovation, government policies, environmental opportunities, and so on are beneficial to the development of the Internet and related industries; Menon et al. [9] analyzed the challenges of product life cycle management and proposed solutions using the openness and related dimensions and subdimensions of the industrial Internet platform; Tang and Dan [10] pointed out that the integrated development of industrial Internet can enhance the creativity of service-oriented manufacturing industry and value in various fields; Muthukumar et al. [11] expound the application of industrial Internet in university education.

In the research on the development of industrial Internet industry and related enterprises, Nivedita and Brem [12] studied the transition and transformation of general electric technology convergence. Yang [13], Yan and Kong [14], and others made a comparative analysis of industrial Internet and German industry 4.0 and put forward policy suggestions for optimizing the industrial Internet industry; Xie and Wu [15] found that industrial agglomeration within a certain range can promote the innovation level of industrial enterprises after 13 years of panel data analysis of industrial industry; Arnold and Voigt [16] collected a questionnaire from 197 companies in Germany and revealed through logistic regression that factors including the relative advantages of the environment, the support from the top management of the company, and the highly competitive market can promote the application of industrial Internet. Beier et al. [17] investigated large and medium-sized enterprises in Liaoning Province and studied how to improve the sustainability of enterprises using industrial Internet from the perspectives of resource efficiency, sustainable energy, and transparency.

At present, the research on the productivity of listed companies has achieved rich results. Today, scholars have used different models and methods to measure the total factor productivity of different industries. Zhang [18] and Keskin and Degirmen [19] used the Malmquist index to conduct a comparative study on the changes of total factor productivity and its components in the Chinese and Turkish banking industry respectively; Cheng and Lu [20] built a model to measure the total factor productivity of industrial enterprises based on Cobb–Douglas production function and added variables such as knowledge capital. Jiang and Jiang [21] used Hicks–Moorsteen TFP index to study the productivity of 16 listed banks and found that the current trend of differentiation of listed banks is obvious. Using the DEA method and financial ratio analysis, Domenico et al. analyzed the changes in financial performance of the Italian KIBS industry and analyzed the interaction between productivity heterogeneity firm localization and firm business sectors [22–24]. At the same time, some scholars have also done research on the methods of OL and LP method [25], ML index [26], and DEA three-stage model [27].

To sum up, previous studies on industrial Internet by scholars covered various disciplines such as engineering, economics, and management. Most of the studies focused on the optimization of technological innovation of industrial Internet platform and the use of industrial Internet platform in different scenarios. The domestic scholars’ analysis of the industrial Internet industry is not deep enough, mostly qualitative analysis and less quantitative analysis, and the estimation of industrial Internet industry productivity is even more inadequate. At the same time, there is a lack of comparative analysis of some industries in industrial Internet. Judging from the known literature, there is no precedent to use the DEA-Malmquist method to study TPtotal factor productivity of the industrial Internet industry. Therefore, we will analyze from the following aspects. First, we take the industrial Internet industry as the analysis object, using data envelopment analysis (DEA) and other methods to explore the change trend of the industrial Internet industry's overall productivity and analyze the situation of total factor productivity from 2015 to 2019 from dynamic and static perspectives. Second, different from the previous literature [28, 29], this paper further subdivides the industrial Internet industry according to the latest industry classification results released by the China Securities Regulatory Commission and measures the difference in the use effect of industrial Internet platforms in different industries.

The rest of this paper is organized as follows. The second section introduces the research methods and data selection methods and explains the selection of input and output
variables and samples. The third section describes the overall and internal characteristics of the industrial Internet industry from the perspectives of dynamic, static, and difference analysis. The fourth section gives the conclusion, policy recommendations, and limitations of this study.

2. Research Methods and Data Selection

2.1. Research Methods and Models

2.1.1. Data Envelopment Analysis Model. Data envelopment analysis (DEA) was first proposed by Charnes et al. in 1978 [30]. Based on the concept of relative efficiency, the DEA method uses nonparametric analysis method to evaluate the relative efficiency of decision-making units with multiple inputs and outputs. Owing to the advantages of reducing errors and simplifying calculations, the DEA method has been widely used in various fields in recent years. The original model of DEA is the DEA-CCR model based on the assumption of constant returns on scale. To solve this problem, a more universal BCC model has emerged. The BCC model optimizes the defect that the CCR model can only measure the technical efficiency (EC) of decision-making units and eliminates the influence of DMU scale. The DEA-BCC model further subdivides EC into the product of pure technical efficiency (PE) and scale efficiency (SE) under the premise that the scale income changes:

\[ EC = PE \times SE. \]  

(1)

\[ SE = \frac{EC}{PE} \] can be obtained through deformation, which can comprehensively measure the efficiency of the object from the perspective of input and output. This paper will adopt the more accurate BCC model to measure the total factor productivity of industrial Internet concept companies from a static perspective.

Output-oriented DEA-BCC model is based on CCR model, which is composed by adding constraint \( \sum_{j=1}^{n} \lambda_j = 1 \), and its programming formula is as follows:

\[
\begin{align*}
\text{min} & \quad \Phi \\
\text{s.t.} & \quad \sum_{j=1}^{n} \lambda_j x_{ij} \leq x_{ik} \\
& \quad \sum_{j=1}^{n} \lambda_j y_{ij} \geq \Phi y_{rk} \\
& \quad \sum_{j=1}^{n} \lambda_j = 1 \\
& \quad \lambda \geq 0 \\
& \quad i = 1, 2, 3, \ldots, m; r = 1, 2, 3, \ldots, q; j = 1, 2, 3, \ldots, n
\end{align*}
\]  

(2)

2.1.2. Malmquist Productivity Index and Decomposition. The Malmquist productivity index was first proposed by the scholar Malmquist in 1953. After several improvements, it was finally widely used. The model adopted in this paper is the Malmquist index improved by Fare, and the formula is as follows:

\[ M_T(X_T, Y_T, X_{T+1}, Y_{T+1}) = SE \times PE \times TC = TFP. \]  

(3)

The increase in total factor productivity is the result of the combined action of technological progress, changes in pure technological efficiency and scale efficiency. When the Malmquist index is greater than 1, the total factor productivity of the decision-making unit has increased. When the index is less than 1, the total factor productivity level can be considered to be in a downward trend.

2.2. Indicator Selection and Description. When using the DEA method to evaluate the industrial Internet industry, the selection of indicators has a great impact on the final output. At present, the evaluation index system of industrial Internet mostly focuses on the industrial Internet platform itself, and the mature index system for evaluating the input-output efficiency of the industrial Internet industry is less. This paper will use the research results of Li (2018) for reference and combine with the “industrial Internet innovation development action plan” issued by the Ministry of Industry and information technology in 2021. At the same time, considering the importance of innovation to industrial Internet enterprises, an industrial Internet industry productivity evaluation index system containing six indicators is constructed. The indicator system includes three output indicators and three input indicators, as shown in Table 1.

The main users of the industrial Internet platform are industrial enterprises. To measure its production efficiency, the input of fixed assets, which is the production equipment of industrial enterprises, should be considered. The input renewal of fixed assets can provide advanced equipment for enterprises [31]. At the same time, increasing R&D input and improving innovation ability are also of great significance to improve the development quality of the enterprises [32]. Therefore, this study takes fixed assets \((X_1)\), the number of research and development personnel \((X_2)\) and research and development expenses \((X_3)\) as input indicators. In the output index, after considering the industrial Internet’s own characteristics and

| Primary indicators | Secondary indicators | Unit | Remarks |
|--------------------|----------------------|------|---------|
| Fixed assets       | Ten thousand yuan    | \(X_1\) |         |
| Number of R&D      | Human                | \(X_2\) |         |
| R&D expenses       | Ten thousand yuan    | \(X_3\) |         |
| Main business cost | Ten thousand yuan    | \(Y_1\) |         |
| Total social       | Ten thousand yuan    | \(Y_2\) |         |
| Trading profit     | Ten thousand yuan    | \(Y_3\) |         |

Data source: calculated by SPSS, version 25.0 software based on public data.
the social and economic benefits of the enterprise, this study chose the main business cost \( Y_1 \), total social contribution \( Y_2 \), and operating profit \( Y_3 \) as the output index. The use of industrial Internet platforms is beneficial to lean management of enterprises [33], thus reducing enterprise costs. Therefore, the improvement of production efficiency can be evaluated through the degree-of-cost reduction of the main business. The total social contribution [34] represents the contribution of the enterprise to society, and the value is the sum of the total wages and benefits, net interest expense, taxes payable, and net profit paid to the employees in the current period. Operating profit measures the economic benefits of an enterprise and reflects the results of its business activities after using the industrial Internet platform.

2.3. Data Selection. As the concept of industrial Internet has not been put forward for a long time and the Internet technology has not been applied to industrial production for a long time, this paper only uses the input-output data of the concept stocks of industrial Internet after 2015 as the sample source. According to the website of Tonghuashun, there are currently more than 120 listed companies classified as industrial Internet concept stocks. Considering that a large number of small and medium-sized enterprises in GEM and science and technology innovation board are not representative, the data of 53 industrial Internet concept stocks listed on the main board before 2015, totaling more than 3,400 data from 2015 to 2019, were finally selected as the productivity measurement objects. The data used in the analysis are all derived from the “Guotai’an” database and the annual reports of various companies from 2015 to 2019. After preliminary collection and collation, some corporate indicators have negative and missing values. In order to avoid the impact of such data that does not meet the requirements of the DEA method, this paper normalizes the collected data. Then, the collected industrial Internet companies are classified and sorted according to the industry division results of the CSRC in the fourth quarter of 2020. It is found that the collected 53 companies are concentrated in four industries: manufacturing, wholesale, and retail; leasing and business services; information transmission; and software and information technology services. Owing to the small number of enterprises in the wholesale and retail industry, leasing and business services, the two industries are collectively named as wholesale and retail and business services for ease of analysis.

Using SPSS25.0 software, descriptive statistical analysis is carried out on the collected raw data of input and output of industrial Internet concept companies from 2015 to 2019. The results are shown in Table 2.

After descriptive analysis, the situation that the standard deviation is higher than the average value is not excessive, and the influence of the extreme value can be determined to be small, which indicates that the statistical analysis has credibility and can be further studied.

3. Empirical Results and Analysis

This study will analyze the total factor productivity of the listed companies of industrial Internet concept stocks from static and dynamic perspectives and combine the difference analysis method to comprehensively analyze the productivity and internal differences of the companies of industrial Internet concept stocks.

3.1. Evaluation of the Static Perspective of Input and Output of Industrial Internet Concept Stocks. We used the DEA-BCC model of DEAP2.1 software to evaluate the EC, PE, and SE of 53 listed companies. The results after sorting are shown in Table 3.

As is shown in Figure 1, except for 2017, when the production efficiency of most companies was in abnormal decline of scale income, the rest of the years were in a state of slight fluctuation. Except for 2017, the number of DEA efficient enterprises accounted for more than 15% from 2015 to 2019, which was close to 20%, indicating that the input-output efficiency of China’s industrial Internet industry was average, and there was a large room for subsequent development.

According to Table 3, it can be concluded that the average value of comprehensive technical efficiency has reached 0.836, indicating that there is still room for improvement in the industrial Internet industry under the existing investment conditions. At the same time, the scale efficiency is generally higher than the pure technical efficiency in the past 5 years, which indicates that China’s industrial Internet industry needs to be strengthened in terms of business management ability and resource allocation level.

The aforementioned analysis points out that the efficiency of each enterprise is too low in 2017. Therefore, this paper makes an input-output redundancy adjustment analysis on industrial Internet enterprises in 2017. After analysis, it is found that only 12 large listed companies (including six manufacturing companies; four information
transmission, software, and information technology service companies; and two wholesale, retail, and business service companies) such as Midea Group, Gree Electronics and Gaohong Co., Ltd. were in the DEA effective state in 2017, with $S^+$ and $S^-$ being 0, and the remaining 41 companies had to carry out redundancy adjustment, indicating that the unreasonable input of production factors in most companies in 2017 resulted in redundancy and low efficiency.

Owing to space limitation, only one enterprise is selected from each of the three subsectors for input-output redundancy adjustment, as shown in Table 4. Taking TCL Technology as an example, it needs to adjust the fixed assets, number of research and development personnel, research and development expenses and operating profit to make DEA effective. Specifically, TCL Technology, which is in the phase of diminishing returns on scale, needs to increase its output by reducing fixed assets by more than RMB2.18 million, reducing 5,300 research and development personnel and reducing research and development expenses by RMB315,800.

Table 3: Analysis of input-output efficiency from 2015 to 2019.

| Years | Comprehensive technical efficiency | Pure technical efficiency | Scale efficiency | Enterprise | Number of DEA effective enterprises |
|-------|-----------------------------------|---------------------------|-----------------|------------|------------------------------------|
| 2015  | 0.847                             | 0.869                     | 0.973           | 28 9 16   | 9                                  |
| 2016  | 0.834                             | 0.858                     | 0.967           | 24 11 18  | 8                                  |
| 2017  | 0.737                             | 0.828                     | 0.893           | 5 7 41    | 5                                  |
| 2018  | 0.884                             | 0.908                     | 0.969           | 39 13 1   | 12                                 |
| 2019  | 0.88                              | 0.902                     | 0.972           | 18 15 20  | 10                                 |
| Mean  | 0.836                             | 0.873                     | 0.955           | 22.8 11 19.2 | 8.8                                |

Data source: calculated by DEAP2.1 software based on public data.

Table 4: Input-output redundancy adjustment of some enterprises in industrial internet.

| Enterprise       | Industry                              | Indicators | S $^-$ | S $^+$ | Target value |
|------------------|---------------------------------------|------------|--------|--------|--------------|
| TCL technology   | Manufacture                           | $Y_1$      | 0      | 0      | 886.64       |
|                  |                                       | $Y_2$      | 0      | 0      | 0.385        |
|                  |                                       | $Y_3$      | 0      | 0.145  | 0.391        |
|                  |                                       | $X_1$      | -218.045 | 0   | 107.935     |
|                  |                                       | $X_2$      | -5,299.63 | 0   | 2,623.37    |
|                  |                                       | $X_3$      | -31.58 | 0      | 15,632      |
| Langchao software| Information transmission, software, and information technology services | $Y_1$      | 0      | 63.918 | 70.808       |
|                  |                                       | $Y_2$      | 0      | 0      | 0.111        |
|                  |                                       | $Y_3$      | 0      | 0.002  | 0.11         |
|                  |                                       | $X_1$      | -0.832 | 0      | 1.028        |
|                  |                                       | $X_2$      | -423.009 | -87.834 | 435.157    |
|                  |                                       | $X_3$      | -1.301 | -0.58 | 1.029        |
| Chuanhua Zhilian | Wholesale, retail, and business services | $Y_1$      | 0      | 0      | 171.7        |
|                  |                                       | $Y_2$      | 0      | 0      | 0.143        |
|                  |                                       | $Y_3$      | 0      | 0.016  | 0.148        |
|                  |                                       | $X_1$      | -3.477 | 0      | 13.233       |
|                  |                                       | $X_2$      | -270.727 | -331.27 | 698.999     |
|                  |                                       | $X_3$      | -0.474 | 0      | 1.804        |

Data source: calculated by DEAP2.1 software based on public data.
3.2. Evaluation of the Dynamic Perspective of Input and Output of Industrial Internet Concept Stocks

3.2.1. Analysis of Total Factor Productivity of Listed Companies with Industrial Internet Concept Stocks. Using DEAP2.1 software to measure the change trend of total factor productivity index of industrial Internet concept companies from 2015 to 2019, the results are shown in Table 5.

According to Table 5, TFP showed a fluctuating downward trend from 2015 to 2019. Total factor productivity decreased by approximately 3.5% in the 5 years. Among them, the changes in technological efficiency, pure technological efficiency and scale efficiency are not significant or slightly increased, while the indicators of technological progress are slightly decreased, which is similar to the overall TFP change trend of industrial Internet. Technological progress is the main factor affecting the total factor productivity of the industrial Internet industry.

After further analysis of the indicators of technological progress, it is found that the indicators of technological progress decreased significantly from 2016 to 2017, which is similar to the change trend of the overall operation efficiency of industrial Internet and slightly lower than the average value of industrial Internet. Among them, the change degree of technological efficiency and pure technological efficiency is higher than that of industrial Internet, and the low level of technological progress leads to the low final total factor productivity, which is consistent with the research results of Wang and Qi [35].

From 2016 to 2017, under the influence of the increasing trend from unreality to falsity, problems such as high taxes and fees and high costs borne by the real industry broke out, resulting in many enterprises’ reduced operating and profitability. After putting forward the idea of turning the false into the real, the total factor productivity of manufacturing enterprises supported by relevant policies immediately rebounded. From 2018 to 2019, affected by the complicated domestic and foreign situations, trade wars, and the increasing downward pressure on the economy, the manufacturing enterprises faced a more severe situation. As a result, total factor productivity declined to a certain extent, but the decline was much lower than that in 2017.

Among the 39 manufacturing enterprises, only five established listed companies, Zoomlion, Midea Group, Xugong Machinery, Foton Motor, and Nangang, are on the rise in operating efficiency, while the other 34 listed companies are on the decline in operating efficiency. Among the indicators of technological progress, only four enterprises (accounting for 10.2% of manufacturing enterprises) are on the rise, and among these four enterprises, except Jianghuai

| Years | Comprehensive technical efficiency | Efficiency change | Pure technical efficiency | Scale efficiency | Total factor productivity |
|-------|-----------------------------------|-------------------|--------------------------|----------------|--------------------------|
| 2015–2016 | 0.975                             | 1.069             | 0.983                    | 0.992          | 1.042                    |
| 2016–2017 | 0.889                             | 0.792             | 0.963                    | 0.923          | 0.704                    |
| 2017–2018 | 1.215                             | 1.001             | 1.118                    | 1.087          | 1.217                    |
| 2018–2019 | 1                                 | 0.973             | 0.995                    | 1.005          | 0.973                    |
| Mean    | 1.013                             | 0.953             | 1.013                    | 1              | 0.965                    |

Data source: calculated by DEAP2.1 software based on public data.

### Table 6: Changes in operation efficiency index of manufacturing enterprises from 2015 to 2019.

| Years | Comprehensive technical efficiency | Efficiency change | Pure technical efficiency | Scale efficiency | Total factor productivity |
|-------|-----------------------------------|-------------------|--------------------------|----------------|--------------------------|
| 2015–2016 | 0.967                             | 1.078             | 0.976                    | 0.991          | 1.043                    |
| 2016–2017 | 0.886                             | 0.795             | 0.955                    | 0.928          | 0.704                    |
| 2017–2018 | 1.251                             | 0.960             | 1.161                    | 1.078          | 1.2                      |
| 2018–2019 | 1.004                             | 0.972             | 0.994                    | 1.01           | 0.975                    |
| Mean    | 1.019                             | 0.946             | 1.018                    | 1              | 0.963                    |

Data source: calculated by DEAP2.1 software based on public data.
Automobile, they are in a state of improving operating efficiency. This is enough to show the importance of improving the management level and scientific research ability of enterprises.

3.2.3. Total Factor Productivity Analysis of Information Transmission, Software and Information Technology Service Enterprises. The following is an analysis of the changes in the annual indices of the operational efficiency of the information transmission, software and information technology services industries. According to Table 7, the total factor productivity of the information transmission, software, and information technology service industry in the past 5 years was 0.964, slightly higher than that of the manufacturing industry of 0.963 and lower than the average value of the industrial Internet industry of 0.965, indicating that the change trend of operating efficiency is similar to that of the manufacturing industry and the industrial Internet industry as a whole. Judging from the breakdown of indicators, all indicators of information transmission, software, and information technology service industry are less than 1, which indicates that the current decline in the development and operation efficiency of this industry is obvious and requires all-round and multilevel development of enterprises. From 2016 to 2017, the total factor productivity of the information transmission, software, and information technology service enterprise industry declined significantly, driven and influenced by technological progress. In 2015~2016 and 2017~2018, when total factor productivity is greater than 1, the technology progress index is higher than 1, indicating that the improvement of technology is of great significance to the production and operation efficiency of enterprises.

In comparison to the operating efficiency of 11 information transmission, software, and information technology service industry enterprises (Table 8), compared with the industrial Internet industry, the information transmission, software, and information technology service industry enterprises are an advantage in terms of technological progress indicators, but there are some deficiencies in the changes in technological efficiency. The changes in pure technological efficiency and scale efficiency are lower than those of the industrial Internet industry. As the industry is dominated by Internet development and application enterprises, these enterprises started late and did not take long to develop. Therefore, many Internet companies still have problems of small scale and low management level, which can improve the reasonable scale and management level of the company while further enhancing the competitiveness of the company’s technical level.

3.2.4. Analysis of Total Factor Productivity within Wholesale, Retail, and Business Services. As shown in Table 9, the average value of total factor productivity in wholesale, retail, and business services from 2015 to 2019 reached 1.001, which is the only industry with total factor productivity...
exceeding 1 in the three industry categories subdivided in this paper. Except for technological progress, the changes in technological efficiency, pure technological efficiency and scale efficiency are all greater than 1. This shows that from the available data, the wholesale, retail, and business service industries have better efficiency in using the industrial Internet platform, and their operating efficiency has been improved. The same as the aforementioned industries, the operating efficiency index of wholesale, retail, and business service enterprises also showed a trend of “rise-sharp decline-sharp rebound-slight correction” over the past 5 years, driven by technological progress.

3.3. Analysis on the Differences of Total Factor Productivity of Enterprises within Industrial Internet. To study the fluctuation and difference of total factor productivity among industries within industrial Internet concept stocks [35], this paper will use standard deviation (SD) and coefficient of variation (CV) for analysis.

\[
SD = \left[ \frac{1}{n} \sum_{k=1}^{n} \left( TFP_k - \overline{TFP} \right)^2 \right]^{1/2},
\]

(4)

\[
CV = \frac{SD}{\overline{TFP}}.
\]

(5)

The specific calculation method is shown in equations (4) and (5). Among them, \( TFP_k \) is the \( k \) industry in industrial Internet concept stocks; \( \overline{TFP} \) is the arithmetic average of all industries.

The results after calculation are shown in Table 10, in which the coefficient of variation over 5 years is less than 15%, indicating that this group of data is in normal fluctuation range. The coefficient of variation is in a trend of rising first and then falling. From 2016 to 2017, each industry has an overinvestment situation. The different degree of overinvestment increases the difference in total factor productivity. Since then, under the government’s macro-control and policy support, various industries within the industrial Internet industry have recovered and developed. By 2018 to 2019, the coefficient of variation has dropped to 0.012, indicating that the degree of difference among various industries in the industrial Internet industry has further narrowed. The change degree of standard deviation is also similar to the fluctuation trend of coefficient of variation, which is in the fluctuation of first rising and then falling.

As can be seen from Figure 2, the wholesale, retail, and business services industries have the most gradual changes, while the vast majority of them have the highest levels. The information transmission, software, and information technology services industry experienced the most drastic fluctuations in the past 5 years. The fluctuation curve of the manufacturing industry and industrial Internet as a whole is relatively consistent, because the number of manufacturing enterprises accounts for more than 73% of the industrial Internet as a whole, so the change in manufacturing industry has a greater impact on the change in industrial Internet industry.

### Table 9: Changes in operation efficiency index of wholesale, retail, and business service enterprises from 2015 to 2019.

| Year | Comprehensive technical efficiency | Efficiency change | Pure technical efficiency | Scale efficiency | Total factor productivity |
|------|-------------------------------------|-------------------|--------------------------|-----------------|--------------------------|
| 2015–2016 | 1.028                              | 1.106             | 1.020                    | 1.008           | 1.137                    |
| 2016–2017 | 1.038                              | 0.770             | 1.024                    | 1.013           | 0.799                    |
| 2017–2018 | 1.037                              | 1.078             | 1.028                    | 1.009           | 1.118                    |
| 2018–2019 | 1.000                              | 0.988             | 1.000                    | 1.000           | 0.988                    |
| Mean    | 1.026                              | 0.976             | 1.018                    | 1.007           | 1.001                    |

Data source: Calculated by DEAP2.1 software based on public data.

### Table 10: Standard deviation and coefficient of variation of total factor productivity in industrial internet industry.

| Year     | Standard deviation | Variable coefficient |
|----------|--------------------|----------------------|
| 2015–2016| 0.052179           | 0.048995             |
| 2016–2017| 0.051383           | 0.070614             |
| 2017–2018| 0.076959           | 0.063708             |
| 2018–2019| 0.011441           | 0.011742             |

Data source: calculated based on total factor productivity.

### Figure 2: Trends of production efficiency of industries in industrial internet. Data source: calculation results in Table 10.
First, from 2015 to 2019, the total factor productivity of China’s industrial Internet industry showed a relatively large fluctuation trend, and the total factor productivity declined slightly. Over the five-year period, total factor productivity fell by about 3.5%, and the change in technical efficiency increased by 1.3%, but the impact of the improvement in technical efficiency was offset by a sharp drop in technological progress of 4.7%. According to the analysis of the financial indicators and data of various companies, in the past 5 years, especially from 2017 to 2019, the proportion of R&D investment was extremely slow, and some companies even experienced negative growth, which led to a decline in technological progress. The main reason for the decline in total factor productivity since 2015 is the decline in technological progress indicators and changes in technical efficiency are the reason for alleviating the decline in total factor productivity. There are differences, which are similar to the research results of Yan Pengfei [36], indicating that new trends and new characteristics have emerged in China’s manufacturing industry since 2015, and the government and enterprises need to adjust relevant strategies under the new situation to adapt to the current situation.

Second, the extreme slump in the industrial Internet industry in 2017 was also the main reason for the decline in total factor productivity. At present, due to the late start of China’s industrial Internet industry, the development is at an immature and low level, and there is also insufficient policy support. Affected by China’s current reform and opening up in the deep water area and the great downward pressure on the economy, the total factor productivity of the industrial Internet industry in 2016–2017 was only 0.704, which caused a huge impact on the entire industry, so far it has not recovered to the level before 2017. The main factor is that most companies overinvest, resulting in diminishing returns to scale for as many as 41 companies, which is similar to the success of Zhang and Wang [29] research. For the situation of excessive investment, industrial Internet companies should improve the efficiency of investment, and timely change the investment plan according to changes in the situation, so as to achieve the goal of improving the efficiency of resource allocation.

Third, in terms of industries, among the enterprises using the industrial Internet platform, the production efficiency of wholesale and retail and business services is the highest, while the production efficiency of manufacturing industry is the lowest, and the production efficiency of information transmission, software, and information technology services lies between them. The differences among the three industries show a trend of increasing first and then decreasing; The fluctuation of information transmission, software, and information technology services is the biggest, which shows that several enterprises in wholesale, retail, and business services use industrial Internet platform better; The productivity of information transmission, software, and information technology services is relatively unstable. Various industries can carry out targeted reinforcement according to the current situation and shortcomings. For example, information transmission, software, and information technology service industries can moderately expand the scale of enterprises, improve scale efficiency, and thus improve total factor productivity; the manufacturing industry pays more attention to technological progress and R&D input efficiency while maintaining the current growth of technological efficiency. At the same time, the government should increase financial support and policy support for the industrial Internet industry, promote industrial Internet enterprises to become bigger and stronger; deepen the synergy of production, education, and research; encourage enterprises to research and develop innovation; and cultivate compound talents in manufacturing and the Internet [37, 38].

The theoretical significance of this research lies in the establishment of an index for evaluating the input-output efficiency of the industrial Internet industry, which promotes research on industrial Internet industry productivity. This paper further subdivides the industrial Internet industry and finds that the effects of industrial Internet platform use are quite different in different industries. These studies are of referential significance for further research on the use of envelope analysis method and industrial Internet productivity research.

This study has certain limitations. First, the concept of industrial Internet was put forward late, the relevant theoretical research was insufficient, and there was no authoritative industrial Internet industry evaluation standard; The number of industrial Internet listed companies is small, and the time for the concept to be put forward is short, which leads to the inability to accurately reflect the development and change trend and fluctuation degree of the industrial Internet industry. Second, in the industry segment, the number of wholesale, retail, and business service enterprises is too small and the sample size is too small. Therefore, the universality and persuasiveness of the analysis results of this industry are not strong enough. If the number of related enterprises increases in the future, horizontal comparison of various industries can be better carried out.

Data Availability

The data used in this study are from the Guotai’an database and the annual report of listed companies.

Conflicts of Interest

The authors declare no conflicts of interest.

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