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Measurement of Green Total Factor Productivity in China's Regional Manufacturing Industry—Taking the Yangtze River Delta Region as an Example

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Abstract: *In order to achieve green and coordinated development of regional manufacturing industry, this article takes the manufacturing industry in the Yangtze River Delta region from 2010 to 2021 as the research object. The super efficiency SBM model with unexpected output and the Malmquist (GML) index with global reference are used to measure the static green development efficiency value and dynamic green total factor productivity value of regional manufacturing industry, and the dynamic green total factor productivity value is decomposed by index, Thus, the dynamic trends and regional differences in the green development of manufacturing industry in the Yangtze River Delta region are studied in terms of time and space dimensions. Research has found that the overall static green total factor productivity of the manufacturing industry in the Yangtze River Delta region is less than 1, which has not reached the forefront of DEA effective production, but shows a slow upward trend. The green development efficiency of the manufacturing industry in different provinces varies greatly, with Shanghai having the highest level of green development in the manufacturing industry. The GML index decomposition shows that the technical efficiency change index is the main factor affecting the green total factor productivity of the manufacturing industry in the Yangtze River Delta region. Therefore, it is necessary to improve the level of resource allocation and green technology innovation in the manufacturing industry of the Yangtze River Delta region; In terms of spatial dimension, the coordination between the development of manufacturing industry and technological innovation in Jiangsu Province is good. However, the growth momentum of green total factor productivity in the manufacturing industry in Shanghai, Anhui, and Zhejiang provinces is insufficient. We must persist in eliminating backward industries and driving innovation.*

Keywords: *Yangtze River Delta region, green total factor productivity*

1. Introduction

China's proposal of "China will increase its national independent contribution and achieve carbon peak before 2030 and carbon neutrality by 2060." This goal means that China will transition from "black development" to "green development" and achieve a rapid and efficient transformation of the green development model under conditions of lower per capita resource endowment and shorter cycles. Therefore, China should pay more attention to the innovative development of green technology and use technology to empower green transformation and development [1].

The high-quality development of the manufacturing industry is a solid foundation for achieving Chinese path to modernization. In the report of the 20th National Congress of the Communist Party of China, it was pointed out that "high-quality development is the primary task of comprehensively building a socialist modernized country. Without a solid material and technological foundation, it is impossible to fully build a socialist modernized strong country. To build a modern industrial system, we must adhere to the focus of economic development on the real economy." [2]. In 2022, China's total industrial added value reached 40 trillion yuan, Accounting for 33.2% of China's GDP; The added value of manufacturing industry accounts for 27.7% of GDP. From the data, it can be seen that the manufacturing industry accounts for a large part of China's real economy, and the green transformation and development of the manufacturing industry is a key link to achieve Chinese path to modernization. At the same time, the green transformation and development of the manufacturing industry is also a key task after the proposal of the "dual carbon" goal. Therefore, whether from a national or domestic perspective, entering the mid-term of the 14th Five Year Plan, China should accelerate the green transformation of its development mode, actively promote green and low-carbon economic and social development, and achieve high-quality development. The green transformation of development mode is mainly driven by green technological innovation, so China should continue to adhere to increasing the investment and attention level of green technological innovation.

This paper analyzes and studies the innovation level of China's regional manufacturing industry from the perspective of green total factor productivity, which is of great practical significance for realizing Chinese path to modernization, promoting the green transformation of China's development mode and achieving the goal of "double carbon", and also helps relevant departments to formulate more reasonable green innovation development strategies. The Yangtze River Delta region is a region with high levels of economic development and technological innovation activity in China. Measuring the green total factor productivity of the manufacturing industry in this region can analyze the existing strategic path and the effectiveness of innovative development ideas based on the calculation results. At the same time, it also has certain reference significance for the green transformation of the manufacturing industry in other regions of China.

2. Literature Review

The 14th Five Year Plan for National Economic and Social Development of the People's Republic of China and the Outline of Long Range Goals for 2035 propose to "maintain a stable proportion of the manufacturing industry, enhance its competitive advantage", and emphasize "promoting high-end, intelligent, and green manufacturing" [3]. China currently has 41 industrial categories, 207 industrial medium categories, and 666 industrial subcategories, with a comprehensive and comprehensive industrial coverage system. In the past decade, China has achieved comprehensive industrialization, and the goal for the next period is also to achieve a green development model of industry. Promoting the high-end, intelligent and green development of manufacturing industry is not only an important task to promote new industrialization in the future, but also a strong support to achieve Chinese path to modernization. After years of scale expansion, the development of China's industrial economy in the domestic market has approached saturation. In the international market, due to the earlier industrial development and better product quality of other countries compared to China, it has become more difficult for China to enter the international industrial market and occupy a high position. Overall, the growth space of the traditional quantitative development model in the past tends to shrink. With the continuous improvement of economic level, the level of market demand is constantly upgrading; At the same time, facing severe international competition pressure, it has become an inevitable choice to lead the manufacturing industry towards high-end and low-carbon development through innovation. Therefore, technological innovation is a key element in transitioning from a traditional manufacturing model to a green manufacturing development model.

Due to the ongoing green transformation of the manufacturing industry and the dominant production mode of traditional manufacturing, further development and in-depth research are needed to measure the green transformation of the manufacturing industry. From previous studies, for the measurement of Chinese path to modernization, the relevant literature is to reconstruct a measurement framework based on previous studies. For example, Cai constructed an evaluation index system for the modernization level of the manufacturing industry chain based on the connotation of China's industrial chain modernization, from four dimensions: industrial organization, innovation ability, economic benefits, and green intensification. The entropy weight method was used to calculate the modernization level index of China's manufacturing industry chain [4]. Based on the five dimensions of the new development concept, Jiang Yong mu constructed the evaluation index system of Chinese path to modernization, which includes five dimensions, 25 system layers, 50 criteria layers and 100 indicator layers, through the dimensional deconstruction at the system level, the systematic analysis at the criteria level, and the criteria measurement at the indicator level. This article divides the innovation dimension into five system layers: innovation input, innovation efficiency, innovation output, innovation ecology, and innovation formats [5]. Cui also constructed an evaluation index system for the basic realization of socialist modernization based on the basic connotation and principles of modernization construction, and determined the weights and target values of each index [6]. Although these articles have reconstructed a new framework for measuring modernization, And Ren ,from the perspective of the core foundation, key content, existing problems, important constraints and basic guarantees of Chinese path to modernization, has constructed an indicator system that includes five statistical dimensions of economic modernization, social process modernization, urban and rural regional modernization, ecological civilization modernization and governance capacity modernization [7]. However, these frameworks have not been adopted in the research of other scholars, so their effectiveness need further verification. And these articles are all designed from the overall perspective for the measurement of Chinese path to modernization, without

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building models for a specific aspect such as green innovation. It is equivalent to only providing a new idea without implementing steps.

Total factor productivity refers to the efficiency of production activities over a certain period of time. It is a productivity indicator that measures the total output per unit of total input. The growth rate of total factor productivity is often regarded as an indicator of technological progress, and its sources include technological progress, organizational innovation, specialization, and production innovation. Du reviewed the research and induction of relevant scholars and found that green total factor productivity combines the ideas of green productivity and total factor productivity [8]. The production efficiency considering resource consumption input and pollution emission output is defined as green total factor productivity (GTFP). Some scholars summarized previous literature and pointed out that the academic community continues to innovate and improve the functional technical model of green total factor productivity, ultimately establishing an analysis of environmental regulatory behavior based on directional distance function.

In recent years, research on green transformation in industrial manufacturing has mainly focused on three aspects: path analysis of green transformation in industrial manufacturing, analysis of influencing factors of green transformation in industrial manufacturing, and measurement analysis of green transformation in industrial manufacturing. Regarding the analysis of the path of green transformation, Zhang Jinhua sorted out four challenges from the perspectives of government, enterprises, and consumers, and elaborated on the four paths of green transformation in China's manufacturing industry under the goal of carbon neutrality [9]; Xie Xuemei , based on the meta theoretical framework of attention based view, selected four typical manufacturing enterprises using a longitudinal multi case study method to deeply analyze the internal formation mechanism of the green transformation evolution process of manufacturing enterprises, which is driven by institutional logic, resource allocation process, and green transformation results [10]. Sun conducted an incomplete review of the research results on the path of green development in the current manufacturing industry, proposing to summarize the path of green development in the manufacturing industry from two dimensions: the research dimension of the behavior subject and the path of green development in the manufacturing industry, including development methods, development paths, and development trends [11]. From the results of path analysis, most of them are analyzed and summarized from four aspects: establishing implementation routes, improving policy systems, strengthening technical support, and promoting the construction of green manufacturing systems. In terms of research on the influencing factors of green transformation in industrial manufacturing, scholars have mainly analyzed and studied factors such as input, output, and external environment. Wan empirically tested the impact of three ways of R&D investment on China's industrial green total factor productivity [12]; Huang used the SBM function and Luenberger productivity index to study the possible bidirectional dynamic relationship between environmental regulation and productivity.

Regarding the measurement of green total factor productivity in industrial manufacturing, Chen estimated the changes in China's industrial total factor productivity using a production function that surpasses logarithmic components and conducted green growth accounting [13]. Chen believes that previous studies have only measured productivity based on traditional capital and labor factors, with little consideration given to energy and environmental factors [14]. However, in actual production processes, unexpected outputs such as exhaust gas, wastewater, and solid waste are inevitably generated simultaneously, resulting in significant external costs. Therefore, in this article, she proposes to use a directional distance function to estimate the total factor productivity of China's industry. Later, many scholars began to use this model to calculate the total factor productivity of industry. Li classified 35 industrial industries in China into resource-based industries, low tech industries, medium tech industries, and high-tech industries [15]. They measured and analyzed the changing trends and differences in GTFP of various industries from 2005 to 2016, and found that the growth of GTFP in low tech industries in China mainly relies on technological progress, while the growth of GTFP in medium and high-tech industries mainly benefits from the improvement of technological efficiency. Chen used directional distance function and ML index to calculate industrial green total factor productivity under resource and environmental constraints, and concluded that high technological level and reasonable property rights structure can significantly improve green total factor productivity [16]. Hou Jian used an improved relaxation measure direction distance function (SBM-DDF) to measure the green transformation performance of technological innovation in 13 high patent intensive manufacturing industries in China, targeting the green ecological transformation of technological innovation in high patent intensive manufacturing industries.[17] Discovery: The green technology innovation performance of China's high patent intensity manufacturing industry has not reached the corresponding matching level, and the heterogeneity characteristics of the industry are obvious. Lei used the EBM-GML model to calculate provincial panel data in China from 2005 to 2017, and obtained green total factor productivity to measure

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the degree of green transformation in China's manufacturing industry [18].

3. Research Method

3.1 Super Efficient SBM Model with Unexpected Outputs

The DEA model (Data Envelopment Analysis), also known as the Data Envelopment Analysis model, is a mathematical optimization technique for evaluating relative efficiency. It is based on linear programming theory, treating all objects to be evaluated as an input-output system, and evaluating their relative efficiency by comparing the input-output indicators of each object. The advantage of data envelopment analysis is that it does not require subjective confirmation of the specific functional equations, features, and construction methods of the model, thus having high flexibility. The traditional DEA methods include the CCR model with constant returns to scale and the BCC model with variable returns to scale. The CCR model and BCC model measure radial efficiency values, only considering radial improvement without considering relaxation improvement. This will result in the measured DMU efficiency value being higher than the actual value. That is, when there is excessive investment or insufficient output, or when there are relaxation variables, radial DEA will overestimate the DMU efficiency value, causing deviation in the measurement results. Therefore, Tone constructed a super efficient SBM model. This model not only solves the problem that the radial model does not include relaxation variables in the measurement of inefficiency, but also effectively distinguishes the size of DMU further. Later, with the development of DEA models, scholars began to incorporate environmental dimensions into their models and developed super efficient SBM models with unexpected outputs. The core idea of this model is to minimize input to the production system, maximize expected output, and minimize unexpected output. Therefore, the super efficient SBM model with unexpected output can comprehensively evaluate the efficiency of the production system compared to traditional data envelopment analysis methods. The specific formula for the super -efficient SBM model with unexpected outputs is as follows:

$$\min\rho = \frac{1 + \frac{1}{m}\sum_{i=1}^{m} s_i^- / x_{ik}}{1 - \frac{1}{q_1 + q_2}\left(\sum_{r=1}^{q_1} s_r^+ / y_{rk} + \sum_{t=1}^{q_2} s_t^{b-} / b_{rk}\right)}$$

$$s.t.\begin{cases}\sum_{j=1,j\neq k}^{n} x_{ij}\lambda_j - s_i^- \leqslant x_{ik}\\ \sum_{j=1,j\neq k}^{n} y_{rj}\lambda_j + s_r^+ \geqslant y_{rk}\\ \sum_{j=1,j\neq k}^{n} b_{tj}\lambda_j - s_r^{b-} \leqslant b_{rk}\\ 1 - \frac{1}{q_1 + q_2}\left(\sum_{r=1}^{q_1} s_r^+ \big/ y_{rk} + \sum_{t=1}^{q_2} s_t^{b-} / b_{rk}\right) > 0\\ \lambda, s^-, s^+ \geqslant 0\\ i = 1,2,\cdots,m; r = 1,2,\cdots,q; j = 1,2,\cdots,n(j \neq k)\end{cases} \tag{1}$$

In equation (1), x_i, y_r, b_r represents input indicators, expected output indicators, and non expected output indicators, respectively; s_i^-, s_r^+, s_r^{b-} represents x_i, y_r, b_r, The relaxation variables corresponding to r represent input redundancy, expected output insufficiency, and unexpected output redundancy; k is the measured DMU; ρ Static green total factor productivity, The larger the ρ's value, the higher the green total factor productivity, when ρ is greater than 1, it indicates that the DMU is located on the DEA effective production front. λ_i is the weight of the cross-sectional observations of the jth province (city).

3.2 GML Index Method

The super efficiency SBM model can only measure the relative efficiency of decision-making units, that is, the measured green total factor productivity is the relative distance between a decision-making unit and the production front during a certain period. It can only provide a static description of the green total factor productivity of the manufacturing industry in various regions and cannot reflect the dynamic trend of green total factor productivity. Therefore, this article selects the Malmquist index (GML) for global reference. This method can not only measure the green total factor productivity with unexpected outputs, but also overcome the limitations of linear solvability and non-transitivity of the ML index. This

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efficiency represents the dynamic changes in green total factor productivity of decision-making units from the t period to the t+1 period. The GML index can be further decomposed into the product of the technical efficiency change index (EC) and the technical progress index (TC). The specific expression is as follows:

$$\begin{aligned} GML_C^G(x^t,y^t,z^t,x^{t+1},y^{t+1},z^{t+1}) &= \frac{E_C^G(x^{t+1},y^{t+1},z^{t+1})}{E_C^G(x^t,y^t,z^t)} \\ &= \frac{E_C^{t+1}(x^{t+1},y^{t+1},z^{t+1})}{E_C^t(x^t,y^t,z^t)} \times \left\{ \frac{E_C^G(x^{t+1},y^{t+1},z^{t+1})}{E_C^{t+1}(x^{t+1},y^{t+1},z^{t+1})} \times \frac{E_C^t(x^t,y^t,z^t)}{E_C^G(x^t,y^t,z^t)} \right\} \\ &= \frac{E_C^{t+1}(x^{t+1},y^{t+1},z^{t+1})}{E_C^t(x^t,y^t,z^t)} \times \frac{TG_C^{G,t+1}(x^{t+1},y^{t+1},z^{t+1})}{TG_C^{G,t}(x^t,y^t,z^t)} \\ &= (GML)EC_C \times (GML)TC_C \end{aligned} \tag{2}$$

From equation (2), it can be seen that the GML index is composed of the technical efficiency change index and the technical progress index. Therefore, the degree of change in green total factor productivity of the manufacturing industry in the Yangtze River Delta region can be analyzed from the perspectives of technical efficiency and technical progress, and the specific influencing factors of green total factor production rate can be analyzed in depth. If the GML index of the experimental results is greater than 1, it indicates that the green total factor productivity of the manufacturing industry in the region has increased compared to the previous year; If the GML index is equal to 1, it indicates that the green total factor productivity of the manufacturing industry in the region has not changed compared to the previous year; On the contrary, if the GML index is less than 1, it means that the green total factor productivity of the manufacturing industry in the region has decreased compared to the previous year.

4. Indicator Selection and Data Sources

In the existing research on the measurement of green total factor productivity in the manufacturing industry, labor, fixed assets investment, energy, etc. are mostly used as input variables, so this paper selects the number of manufacturing workers, fixed asset investment, and energy consumption in the Yangtze River Delta region from 2010 to 2021 as input variables of the experimental data.

4.1 Input Indicators

Capital investment. Based on the feasibility of the data, the annual fixed assets investment of manufacturing industry in each province is selected as the capital input variable. In order to eliminate the impact of price factors, the fixed assets investment price index is used to reduce the amount of fixed assets investment with 2010 as the base period.

4.2 Output Indicators

(1) The total output value of the manufacturing industry. Selecting the total output value of the manufacturing industry in each province as the expected output variable, in order to eliminate the influence of price factors, using 2010 as the base period, the industrial product factory price index was used to deflate the data, and the deflated data was used as experimental data.

(2) Carbon emissions. At present, there are various methods for calculating carbon emissions, such as "top-down" and "bottom-up". This article uses a "top-down" calculation method to estimate the carbon emissions of the manufacturing industry in the Yangtze River Delta region using various energy consumption and energy carbon emission coefficients. The specific calculation formula is as follows:

$$C = \frac{44}{12}\sum_{i=1}^{n} E_i \times e_i \times \rho_i$$

In the formula, C represents carbon emissions and i represents the type of energy. This article calculates raw coal. Carbon emissions of gasoline, diesel, and kerosene, E_i is the consumption of energy i. e_i is the converted standard coal coefficient of energy i, ρ_i is the carbon emission coefficient of energy i.

The input-output data involved in the article are all from the statistical yearbooks of various provinces in the Yangtze River Delta region. The energy conversion standard coal coefficient and energy carbon emission coefficient are sourced from the "2006 IPCC Guidelines for National Greenhouse Gas

Inventories".

4.3 Descriptive Statistics

Table 1 presents descriptive statistics for each indicator data. From Table 1, it can be seen that due to the different levels of manufacturing development in each province (city), there is a significant difference in input-output data among provinces (cities) in the Yangtze River Delta region, which may also lead to significant differences in the value of green total factor productivity of manufacturing in each province (city). Therefore, it is necessary to measure and compare the green total factor productivity of the manufacturing industry in various provinces (cities) in the Yangtze River Delta, in order to achieve coordinated green development of the manufacturing industry in the region.

Table 1: Descriptive Statistics of input-output Variables of Green Total Factor Productivity

Indicator variables	Number of samples	Maximum value	Minimum value	Range	Standard deviation
Annual average number of employees (10000 people)	12	1122.79	169.77	953.02	287.25
Annual investment in fixed assets (100 million yuan)	12	29022.73	718.06	28304	7402.86
Energy Consumption (10000 tons tce)	12	17938.59	357.86	17580	6262.02
Total output value (100 million yuan)	12	212083.80	15711.8	196371	51680.94
Carbon emissions (100 million CO_2)	12	125771.67	2728.70	123042	43732.07

5. Empirical Result Analysis

5.1 Measurement and Analysis of Static Green Total Factor Productivity in Manufacturing Industry

This article is based on the unexpected super efficiency SBM model and the input-output data of the manufacturing industry in the Yangtze River Delta region from 2010 to 2021. Matlab2021b software is used to calculate the static green total factor productivity of the manufacturing industry in the Yangtze River Delta region during the sample period, and data analysis is conducted on the calculation results. A trend chart of green total factor productivity changes is drawn as shown in Figure 1, Subsequent studies in this article have chosen to measure the green total factor productivity of the manufacturing industry under the constraint of constant returns to scale.

From Figure 1, it can be seen that the green total factor productivity of the manufacturing industry in the Yangtze River Delta region has shown a trend of first stabilizing and then fluctuating in the past 12 years, but the average value is 0.667, indicating that the overall green total factor productivity of the manufacturing industry in the Yangtze River Delta region has not yet reached the DEA effective frontier, and the input-output efficiency is relatively low. During the inspection period, the increase in green total factor productivity in the Yangtze River Delta region remained basically unchanged from 2010 to 2017, but it significantly increased in 2018 and reached its peak in 2018, with a peak of 0.876, followed by a fluctuating upward trend. The possible reason for this is that the international financial crisis that broke out in 2008 hindered the export and overcapacity of manufacturing enterprises in the Yangtze River Delta region, resulting in a significant decrease in corporate profits. After the crisis, enterprises have to use a large amount of energy to expand production in order to improve their living conditions, while neglecting to improve energy technology and environmental protection, resulting in green total factor productivity remaining at a relatively low level. In 2018, the integration strategy of the Yangtze River Delta was officially upgraded to a national strategy, which enabled the manufacturing industry in the Yangtze River Delta region to receive more national policy and financial support, helping manufacturing enterprises increase research and development of green production technologies, improve clean production and green processes, and promote sustainable development of the manufacturing industry; It can also achieve interconnection and coordinated development of the manufacturing industry in the Yangtze River Delta region, initiate a series of modern industrial park construction, and promote the transformation and upgrading of industrial structure towards high-end, intelligent, and environmentally friendly directions. Therefore, in 2018, the static green total factor productivity of the manufacturing industry in the Yangtze River Delta region increased significantly compared to previous years, and although it decreased in the following years, it showed a fluctuating upward trend.

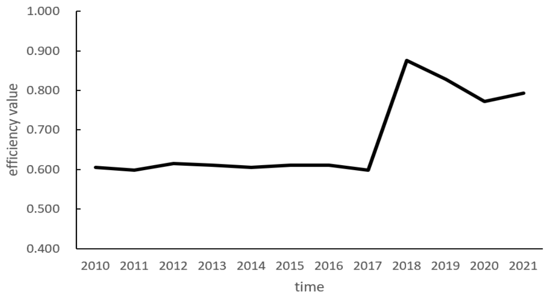

Figure 1: Trends in Static Green Total Factor Productivity of the Manufacturing Industry in the Yangtze River Delta Region from 2010 to 2021

In order to observe the specific trend of static green total factor productivity in the manufacturing industry of various provinces (cities) in the Yangtze River Delta region in more detail and accurately, Figure 2 shows the line chart of static green total factor productivity values in the manufacturing industry of Jiangsu Province, Zhejiang Province, Shanghai City, and Anhui Province from 2010 to 2021. From Figure 2, it can be seen that there are significant differences in the static total factor productivity of the manufacturing industry among provinces (cities) in the Yangtze River Delta region. According to the overall ranking of static green total factor productivity in the manufacturing industry, Shanghai, Jiangsu Province, Zhejiang Province, and Anhui Province rank from high to low. During the sample period, the static green total factor productivity of Shanghai's manufacturing industry was all greater than 1, with an average of 1.715, which is much higher than the other three provinces. This indicates that labor, capital, energy and other inputs in Shanghai's manufacturing industry can be well utilized, and both expected and unexpected outputs have reached expected levels. The green development level of the regional manufacturing industry is good. The trend of static green total factor productivity in the manufacturing industry of Jiangsu Province is similar to the overall trend in the Yangtze River Delta region. From 2010 to 2017, the static green total factor productivity of the manufacturing industry remained basically unchanged, with an average of 0.307. In 2018, it significantly increased and exceeded 1 for the first time, reaching the forefront of DEA effective production, and remained at a level greater than 1 from 2019 to 2021. This is because: firstly, in 2018, Jiangsu Province actively implemented the "Implementation Plan for the Construction of Jiangsu Province's Green Manufacturing System", eliminated low-end and inefficient production capacity, created a model of green advanced manufacturing, and promoted the construction of a green manufacturing system. The trend of changes in Zhejiang Province and Anhui Province is similar. During the sample period, both reached their first peak in 2012 and then began to decline. It was not until 2018 that they rose again and reached their second peak. However, after 2019, they began to decline again. However, in 2021, the static green total factor productivity of the manufacturing industry in Anhui Province continued to decline, while the static green total factor productivity of the manufacturing industry in Zhejiang Province once again showed an upward trend. However, the static green total factor productivity of Zhejiang and Anhui has not reached the effective frontier of DEA production for a year. This may be due to the short time it took for Anhui Province to join the Yangtze River Delta regional integration strategy, the insufficient reflection of high-quality development dividends, and the fact that there are many resource-based cities in the province and the difficulty of transformation, resulting in a lower overall green development level of the manufacturing industry in Anhui Province. Although Zhejiang Province is adjacent to Shanghai, due to constraints such as lagging manufacturing technology, poor management, and insufficient investment, it is difficult to fully absorb Shanghai's green technology innovation spillovers, resulting in low static green total factor productivity.

From the perspective of static green total factor productivity, overall, the manufacturing industry in the Yangtze River Delta region remained basically unchanged from 2010 to 2017, and has significantly improved since 2018, but has not yet reached DEA effectiveness. From a specific province perspective, the static green total factor productivity of the manufacturing industry in Shanghai, a leading city in the Yangtze River Delta region, has always been greater than 1. Jiangsu Province also exceeded 1 for the first time in 2018 and maintained above 1. However, Zhejiang and Anhui have not yet reached DEA efficiency, with relatively small changes and values much lower than those in Shanghai and Jiangsu. In other words, the significant increase in static green total factor productivity of the manufacturing industry in the Yangtze River Delta region in 2018 was mainly contributed by Jiangsu Province. In order to achieve high-quality development of the manufacturing industry in the Yangtze River Delta region, Zhejiang and Anhui should timely adjust investment indicators and focus on industrial transformation, in order to improve the green total factor productivity of the manufacturing industry.

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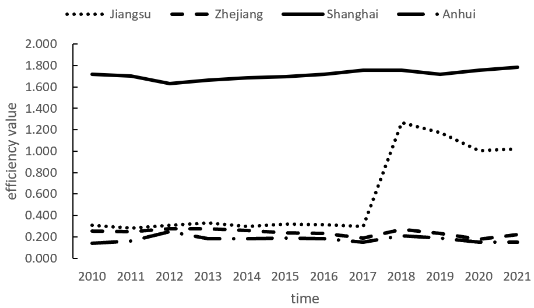

Figure 2: Line chart of static green total factor productivity values of manufacturing industries in various provinces of the Yangtze River Delta from 2010 to 2021

5.2 Analysis of Dynamic Green Total Factor Productivity Changes in Manufacturing Industry

The previous section calculated the static green total factor productivity of the manufacturing industry in the Yangtze River Delta region from 2010 to 2021 based on the SBM model with unexpected outputs. In order to further investigate the impact of technological efficiency changes, technological progress, and other technological changes on the green total factor productivity of regional manufacturing industry, and observe the dynamic changes of total factor productivity values in various years within the research time interval, this article also uses the global reference Malmquist index (GML index) to decompose the green total factor productivity values of the manufacturing industry in the Yangtze River Delta region using the GML index, and observes the overall changes based on the geometric mean.

5.2.1 Time Dimension

The overall GML index and its decomposition values in the Yangtze River Delta region are shown in Table 2, and the trend chart is shown in Figure 3. Table 2 shows the average value of manufacturing total factor productivity in the Yangtze River Delta region from 2010 to 2021, which is 1.0674, indicating that the annual average growth rate of dynamic green total factor productivity in the Yangtze River Delta region from 2010 to 2021 was 6.74%. From Figure 3, it can also be seen that the overall dynamic green total factor productivity of the manufacturing industry in the Yangtze River Delta region shows a fluctuating upward trend. The technical efficiency change index increased by 5.71% (the average annual value of the technical efficiency change index was 1.0571), and the technical progress index increased by 1.45% (the average annual value of the technical progress index was 1.0145), indicating that the growth of technical efficiency is the main driving factor for the increase in dynamic total factor productivity of the manufacturing industry in the Yangtze River Delta region, and there is still great room for improvement in the driving role of technological progress in improving dynamic total factor productivity. In other words, if the total factor productivity exceeds 1, it can indicate that the GML index will increase at an average annual rate of 6.74% during the experimental period set in this article. From the table, it can be seen that the years of total factor productivity growth are as follows: 2010-2011, 2011-2012, 2014-2015, 2015-2016, 2016-2017, and 2017-2018. Compared with the previous period, each period has increased in total factor productivity, accounting for 54.5%; The technological progress index has also exceeded 1, indicating an increasing trend in the technological progress of the manufacturing industry in the Yangtze River Delta region. The research and development of high-end technologies in the manufacturing industry has been effective, and it can be seen that the innovation effect is significant; The technical efficiency index also exceeded 1, but the excess was not significant, indicating a certain range of improvement in the technical efficiency value of the manufacturing industry. Compared to this, the increase was not significant. At this level, the existing innovative elements of the manufacturing industry in the Yangtze River Delta region are sufficient, but there is still room for optimization in the input-output ratio of related technology research and development, as well as in the allocation of resources such as production, innovation, and management.

Table 2: Manufacturing GML Index and Its Decomposition Values in the Yangtze River Delta Region from 2010 to 2021

Time	GML	EC	TC
2010-2011	1.0875	1.0101	1.0758
2011-2012	1.1178	1.0613	1.0551
2012-2013	1.1017	1.0897	1.0124
2013-2014	1.0650	1.0812	0.9838

2014-2015	1.1106	1.1724	0.9493
2015-2016	1.1202	1.1616	0.9681
2016-2017	1.1211	1.1328	0.9957
2017-2018	1.1404	1.1489	0.9991
2018-2019	0.9742	0.9521	1.0242
2019-2020	0.9483	0.9132	1.0400
2020-2021	0.9543	0.9044	1.0557
Geometric mean	1.0674	1.0571	1.0145

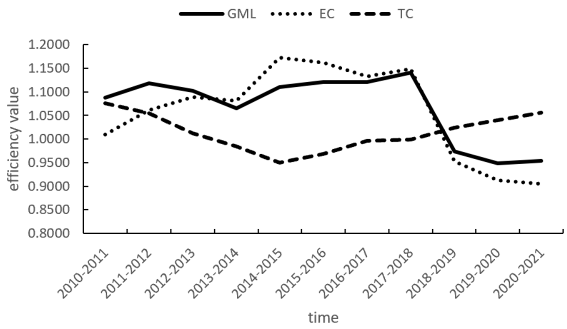

Figure 3: Regional Manufacturing GML Index and Its Decomposition Value Trend Line Chart

In order to more specifically analyze the dynamic trends and phased characteristics of GML index, technological efficiency change index, and technological progress index that change over time, this article also divides time into three parts for research: the first stage is from 2010 to 2011, during which the technological progress index is greater than the technological efficiency change index, and the GML index is around 1.10 and steadily rising. The second stage is from 2011 to 2019. During this period, on the contrary, the index of technological efficiency change is greater than the index of technological progress in each year, and the GML index is also all greater than 1, indicating that the main driving force for the dynamic green total factor productivity improvement of the manufacturing industry in the Yangtze River Delta region is the index of technological efficiency change. Specifically, from 2014 to 2015, the technical efficiency change index reached its highest point, with a value of 1.1724, and the technical progress reached its lowest point, with a value of 0.9493. However, at this time, the GML index was still greater than 1, with a value of 1.1106. Because the growth rate of technical efficiency was much greater than the decline rate of technical progress, the GML index of the manufacturing industry in the Yangtze River Delta region still showed an upward trend during this period. The second stage is from 2018 to 2021, during which the technical efficiency change index is less than the technical progress index, and the GML index is all less than 1. Although the technological progress index has exceeded 1 at this stage, the growth rate of the technological progress index is much smaller than the decrease in technological efficiency. Technological progress is insufficient to offset the decrease in technological efficiency, so the GML index is less than 1. So in the future, the manufacturing industry in the Yangtze River Delta region should not only strengthen technological research and development, cultivate technical talents, promote technological innovation and progress, but also reasonably allocate resources, optimize production processes, improve technological efficiency, and promote the improvement of green total factor productivity in the manufacturing industry in both directions.

5.2.2 Spatial Dimension

Due to heterogeneity differences in the Yangtze River Delta region, the efficiency values of manufacturing development vary among provinces. In order to further explore the specific factors that affect the efficiency of manufacturing development, This article decomposes the GML index of various provinces in the Yangtze River Delta region, and the decomposition results are shown in Figure 4. From the trend of GML index changes in various provinces of the Yangtze River Delta region during the experimental period shown in Figure 4, it can be seen that the GML index and technological progress index trends in Jiangsu Province and Shanghai City are largely similar. Therefore, it can be considered that the changes in technological progress index affect the changes in total factor productivity in these two provinces and cities at a large level. The three indices in Zhejiang and Anhui provinces have different trends over time, further indicating that the changes in both the technical efficiency index and the technical progress index jointly affect the changes in total factor productivity.

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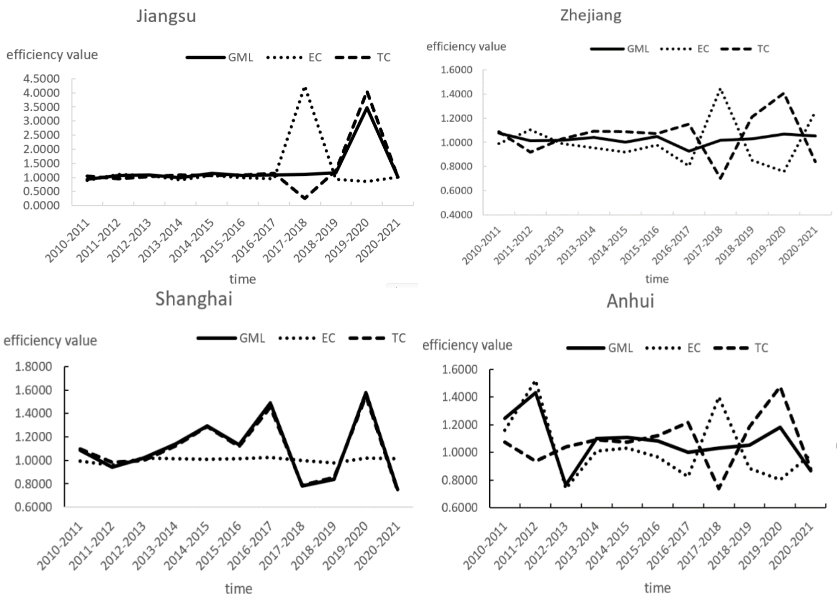

Figure 4: Line Chart of Manufacturing GML Index and Its Decomposition Values in Various Provinces of the Yangtze River Delta from 2010 to 2021

From Figure 5, it can be seen that the annual average GML index of each province in the Yangtze River Delta from 2010 to 2021 was greater than 1, indicating that the overall green total factor productivity of the manufacturing industry in each province was growing during this period. The annual average GML index of Jiangsu, Zhejiang, Shanghai, and Anhui were 1.2839, 1.0270, 1.0955, and 1.0793, respectively. From this data, it can be seen that the green development of the manufacturing industry in various provinces in the Yangtze River Delta region is not balanced. There is a significant gap in the efficiency of green development between provinces. The green total factor growth rate of the manufacturing industry in Zhejiang Province is only 2.7%. Therefore, it is necessary to strengthen the breakthroughs in core technology and the transformation and upgrading of enterprise production in Zhejiang Province's manufacturing industry, leverage the driving and assistance role of high-level manufacturing development cities in surrounding areas, promote knowledge sharing and technology introduction, and promote the balanced development of the manufacturing industry in the Yangtze River Delta region.

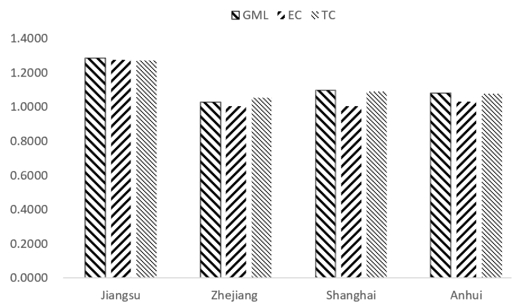

Figure 5: 2010-2021 Manufacturing GML Index and Its Decomposition Value Histogram of Various Provinces in the Yangtze River Delta Region

Compared with Shanghai, the total factor productivity of manufacturing industry in Jiangsu Province has increased rapidly, especially in Jiangsu Province. Through calculation, it is found that the average annual growth rate has reached 28.39% (the annual average of GML index is 1.2839). Most of the reasons for this phenomenon are that under the background of the "new normal" economy in recent years, Jiangsu Province has steadily promoted the supply side structural reform in combination with its location and resource endowment advantages, A stable economic development trend has been achieved. Under such a development background, the main income, operating income and per capita income of Industrial Enterprises above designated size are relatively stable among the top five in China. The industry layout is targeted. The capital intensive traditional manufacturing industry coexists with a part of the new manufacturing industry that has achieved transformation and upgrading, and has broad development prospects. The innovation and breakthrough of key core technologies in the medium and high-end manufacturing industry have been effective, and the promotion and application have begun to take shape.

Followed by Shanghai and Anhui Province, the average annual growth rate is 9.55% and 7.93% respectively (the annual average of GML index is 1.0955 and 1.0793 respectively). The average annual growth rate of Zhejiang Province is only 2.7%, which is mainly due to the relatively low labor productivity and industrial value-added rate of manufacturing industry in Zhejiang Province, resulting in the relatively low level of total factor productivity of manufacturing industry; Zhejiang's industrial investment, especially in manufacturing, is insufficient, and the driving force of innovation is still insufficient. The unit energy consumption and unit carbon emissions of the manufacturing industry are relatively high, and there is still room for improvement in the transformation efficiency and factor support capacity of technological breakthroughs. From the overall perspective, the spatial dimension of total factor productivity growth in the Yangtze River Delta region shows the characteristics of rapid growth in Jiangsu Province, parallel growth in Shanghai and Anhui Province, and slow growth in Zhejiang Province.

From the perspective of GML index decomposition values, firstly, the total factor productivity of the manufacturing industry in Jiangsu Province can be said to be driven by both technological efficiency and technological progress. 1. 2561 and 1 The technological efficiency change index and technological progress index of 2549 have surpassed the other three provinces (autonomous regions) in the Yangtze River Delta region, resulting in the fastest growth rate of total factor productivity in Zhejiang Province's manufacturing industry compared to other provinces. It can be seen that in order to improve total factor productivity in regional manufacturing, emphasis should be placed on cultivating resource allocation capabilities, tapping into the potential for technological progress and development, and supporting the rapid transformation of technological innovation achievements in industry, academia, and research. Secondly, it is calculated that the change index of manufacturing technology efficiency and the technology progress index in Shanghai are 1 0062 and 1 1005, the technological progress index can be seen to be above 1, but the calculated annual growth rate is only 0 05%, the growth rate of technological progress and development is limited. Subsequently, the calculated change index of manufacturing technology efficiency in Anhui Province was 1 0663, with a technological progress index of 1.0513, Anhui Province is cultivating specialized, refined, and innovative high-tech enterprises according to the manufacturing hierarchy path of "mass entrepreneurship and innovation → high growth small and micro enterprises → scale enterprises → specialized, refined, and innovative → small giants (individual champions) → leading enterprises". However, it still faces problems such as limited industrial models, small coverage of production standards, and the need to break through high-end manufacturing levels, which has become a necessary step for the high-quality development of the manufacturing industry. Finally, the index of technological efficiency change in Zhejiang Province is 1 0095, with a technological progress index of 1.0541, also indicating that the slow progress and low technological efficiency have constrained the improvement of total factor productivity in Zhejiang Province's manufacturing industry.

From this, it can be seen that there are obvious regional differences and imbalances in the development of the manufacturing industry in the four provinces (autonomous regions), with significant differences in the driving forces of total factor productivity growth. The coordination between the development of the manufacturing industry in Jiangsu Province and technological innovation is good, while the green total factor productivity growth momentum of the manufacturing industry in Shanghai, Anhui, and Zhejiang provinces is insufficient. We must persist in eliminating backward industries and promoting innovation.

6. Conclusions and Recommendations

6.1 Conclusions

This article uses the super efficiency SBM model with unexpected outputs and the Malmquist (GML) index with global reference to calculate the static green development efficiency and dynamic green total factor productivity values of the manufacturing industry development in the Yangtze River Delta region from 2010 to 2021, and conducts comparative analysis from the time and spatial dimensions. The research results show that: (1) The green total factor productivity of the manufacturing industry in the Yangtze River Delta region has shown a trend of first stabilizing and then fluctuating in the past 12 years, but the average value is 0.667, indicating that the overall green total factor productivity of the manufacturing industry in the Yangtze River Delta region has not yet reached the DEA effective frontier, and the input-output efficiency is relatively low. There is a significant gap in static green total factor productivity among provinces, with an overall trend of unreasonable resource allocation and imbalanced

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development such as excessive investment and insufficient output. Among them, Shanghai has the highest level of green development in the manufacturing industry; (2) From the perspective of time evolution, green total factor productivity is greater than 1, and the main factor driving green total factor productivity is the change in technological efficiency. This indicates that the manufacturing industry in the Yangtze River Delta region actively adopts new technologies, equipment, processes, and management methods, thereby improving resource utilization efficiency and production efficiency. (3) From a spatial perspective, there are significant regional differences and imbalances in the development of the manufacturing industry in the four provinces (autonomous regions), with significant differences in the driving forces of total factor productivity growth. Jiangsu Province has a good coordination between manufacturing development and technological innovation, while Shanghai, Anhui, and Zhejiang provinces have insufficient driving forces for green total factor productivity growth in the manufacturing industry. It is necessary to adhere to the elimination of backward industries and the drive for innovation.

6.2 Recommendations

Overall, the development level of the manufacturing industry in the Yangtze River Delta region is relatively good and stable, and the spatial differences between provinces have also improved. However, compared to other regions, there is a phenomenon of extreme imbalance in development. This article proposes that efficient regions (such as Shanghai) can provide technical support to inefficient regions, helping them improve manufacturing technology and production efficiency by sharing technological innovation, research and development achievements, and practical experience. High efficiency regions can also cooperate with low efficiency regions, achieving complementary advantages through industrial chain collaboration, resource integration, division of labor collaboration, and jointly improving the development level and competitiveness of the manufacturing industry.

Strengthen the research and promotion of key core technologies for green innovation in the manufacturing industry, and improve resource utilization efficiency on the basis of existing factor endowments. With the transformation and upgrading of green and high-end manufacturing industry, the demand for technology continues to expand. The original traditional manufacturing equipment can no longer meet the market demand for high-end manufacturing production, and high-end manufacturing equipment technology urgently needs to break through innovation. Therefore, it is necessary to accelerate the breakthrough of key core technologies and promote the development of high-end manufacturing industry; From the perspective of top-level design, national and local governments should also promote "unveiling and leading", encourage technological research and development innovation, increase policy subsidies for key core technology research and development, including low-carbon, energy-saving and other manufacturing related equipment, and enhance the core driving force of innovative technology for the development of the manufacturing industry;

The improvement of the manufacturing governance system and governance capabilities is crucial for the high-quality development of the manufacturing industry. Firstly, it is necessary to formulate and improve legal systems, establish a management system for the short manufacturing industry, regulate enterprise and market behavior, and enhance governance efficiency; Secondly, we need to strengthen the reform of institutional mechanisms, promote tax reduction and fee reduction, optimize the market environment, and enhance competitiveness and innovation momentum; We also need to promote the development of informatization, strengthen the application of advanced technologies such as big data and artificial intelligence in the manufacturing industry, and improve production efficiency and quality level.

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