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Measurement, Decomposition of Drivers and Evolution of Green Financial Efficiency in the Yangtze River Delta Region

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Abstract

This study aims to measure and analyze the green financial efficiency in the Yangtze River Delta region, and to explore its motivation and its evolution trend. By constructing a green financial efficiency evaluation index system and using the static DEA-CCR model, the dynamic DEA-Malmquist model, and the kernel density analysis, the study analyzes the dynamic measurement decomposition and the evolution of the driving mechanism of green financial efficiency in the Yangtze River Delta region. It is found that the overall green financial efficiency in the Yangtze River Delta region shows a fluctuating upward trend, and technological progress is the main driving force to improve efficiency. However, there is a significant imbalance between regions, and the growth rate of green financial efficiency in Shanghai is significantly faster than that in Anhui Province. The analysis of drivers indicates that the level of technological innovation is a key factor affecting green financial efficiency. This study further explores the evolutionary path of green financial efficiency in the Yangtze River Delta region, pointing out that technological innovation should be strengthened, the green financial system should be improved, and regional cooperation should be increased in order to promote the improvement of green financial efficiency and the green transformation of the regional economy.

Keywords

Green Finance; Efficiency Measurement; DEA-CCR Model; Driver Decomposition; Evolution.

1. Introduction

As the world attaches increasing importance to environmental protection and sustainable development, green finance has emerged as a key force in promoting the green transformation of the economy. The Yangtze River Delta (YRD) is one of the most economically prosperous and innovative regions in China, and the exploration and practice of green finance is of great significance to the realization of green and low-carbon development in the region and the whole country. At the same time, according to the Outline of the Plan for the Integrated Development of the Yangtze River Delta, the Yangtze River Delta region is also tasked with the important mission of taking the lead in exploring the innovative development model of green finance and providing replicable experience for the whole country.

Kee En Lim (2022) proposes that green finance encompasses multiple dimensions such as environmental risk management, sustainable investment strategy, and financial product innovation, which not only includes direct financial support for green projects, but also includes the consideration of environmental factors in the daily operation of financial institutions, so as to reduce pollution to the environment and move closer to sustainability, which has ushered in a wave of green finance in China. At the same time, green financial efficiency, as a core indicator of the effectiveness of the financial system, clearly indicates the intrinsic relationship between financial inputs and green outputs. This study intends to comprehensively utilize cutting-edge

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economic analysis methods and rich data resources to comprehensively and systematically measure the efficiency of green finance in the Yangtze River Delta region, deeply analyze the multiple drivers affecting the efficiency, and depict in detail the trajectory of its evolution, with a view to providing a strong basis for decision-making and academic support for the high-quality development of green finance in the region.

2. Literature Review

In the field of green financial efficiency measurement, early research mostly utilized the single-indicator evaluation method, where the ratio of green credit balance to total loan balance was used to measure the level of green financial development (Ma Jun, 2015). However, this approach is difficult to fully present the input-output association of green finance. Therefore, the data envelopment analysis (DEA) method has gradually become the mainstream.The CCR model proposed by Charnes (1978) is the classic paradigm of DEA method, which is used to evaluate the relative efficiency of decision-making units (DMUs), and many scholars apply it to the measurement of green financial efficiency, which is also applied in this paper for the measurement of green financial efficiency. Regarding the influencing factors of green financial efficiency, there are also many scholars in China who give their views, how Lingyun (2019) found through empirical research that the implementation of green financial policy significantly improves the regional green financial efficiency, and the policy is more effective in the eastern region.

For the evolution of green financial efficiency, existing studies are relatively few and mainly focus on time series analysis. China's Ding Yu (2023) used the Malmquist index method to analyze the evolution of green financial efficiency in China's provinces and found that China's green financial efficiency as a whole shows an upward trend, but there are differences in the speed of evolution and driving factors in different regions, the eastern region mainly relies on technological advances to promote the improvement of green financial efficiency, while the central and western regions rely more on the improvement of technological efficiency, and this paper also analyzes the evolution of green finance from the Malmquist index method and decomposes it into a series. Malmquist index method and its decomposition to analyze the evolution of green finance.

To summarize, scholars at home and abroad have gained rich research results in the connotation, efficiency measurement, influencing factors and evolution of green finance, but there are still some shortcomings. For example, the choice of green financial efficiency measurement methods has not yet formed a unified specification, and the applicability and limitations of different methods still need to be further explored; in the study of influencing factors, the interaction between factors and the heterogeneity of different regions and industries need to be analyzed in depth; in the study of the evolution of green financial efficiency, it focuses on the analysis of the time dimension, and is still weak in the study of the dynamic change of the spatial dimension and the mechanism of synergistic evolution between regions. The research on the evolution of green financial efficiency focuses on the analysis of the time dimension, and the research on the dynamic changes in the spatial dimension and the synergistic mechanism between regions is weak. Based on the existing research results, this study will conduct a more in-depth and systematic investigation on the measurement, decomposition and evolution of green financial efficiency in the Yangtze River Delta region to make up for the shortcomings of the existing research and provide more targeted policy recommendations for the development of green finance in the region, so as to enable the development of green finance in the Yangtze River Delta region to take the lead in the development of green finance in the whole country.

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3. Research Methodology

3.1. Static DEA-CCR Models

The DEA model is based on relative efficiency ratios and comparative analysis of the characteristics and information of specific objects in order to assess the efficiency of decision-making units. The advantage of this method is that the efficiency of several decision-making units with different inputs and outputs can be directly assessed without the need to harmonize the scale of indicators. This study chooses to adopt the CCR model to measure and assess the green financial efficiency of the Yangtze River Delta region from a static perspective. The model formula is shown in equation (1).

Where,θ is the value of efficiency rating; x is the input vector; y is the output vector;j $= 1,2,\cdots,$ n is the decision unit;λ_j is the combination of coefficients of each unit;s^-s^+ is the slack variable. The meaning of the DEA model formula is: if ,$\theta = 1 s^+ \neq 0$, or ,$s^- \neq 0 \theta < 1$ then it indicates that the value of the measured efficiency is relatively ineffective.

$$\begin{cases} \min\left[\theta - \varepsilon\left(\sum_{j=1}^{n} s^- + \sum_{j=1}^{n} s^+\right)\right] \\ \text{s. t.} \sum_{j=1}^{n} \lambda_j x_j + s^+ + \theta x_0, \sum_{j=1}^{n} \lambda_j y_j - s^- = y_0 \\ \lambda_j \geq 0, s^+ \geq 0, s^- \geq 0, j = 1,2,\cdots,n \end{cases} \quad (1)$$

3.2. Dynamic DEA-Malmquist Exponential Modeling

The model studies the dynamic evolution of efficiency from a micro perspective, makes up for the shortcomings of the traditional DEA method that cannot analyze continuous time series, and incorporates the factor of technological progress into it (Bankeretal.1984). The model formula is shown in equation (2).

$$M_0^t = \frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)} \quad (2)$$

Where: d0 is the distance function. Equation (2) measures the change in productivity from t to (t+1) under technological conditions at time t using the Malmquist index. The index can also measure the change in productivity from t to (t+1) under technological conditions at time (t+1), as shown in equation (3) (Bankeret al. 1984).

$$M_0^{t+1} = \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^t, y^t)} \quad (3)$$

In measuring the Malmquist index, the geometric mean of equations (2) and (3) is usually used to express the change in productivity from time t to (t+1) as shown in equation (4).

$$\begin{aligned} M_0 &= [M_0^t \times M_0^{t+1}]^{\frac{1}{2}} \\ &= \left[\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)} \times \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^t, y^t)}\right]^{\frac{1}{2}} = \text{Effch} \times \text{Techch} \\ &= \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)} \left[\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})} \times \frac{D_0^t(x^t, y^t)}{D_0^{t+1}(x^t, y^t)}\right]^{\frac{1}{2}} = \text{Pech} \times \text{Sech} \times \text{Techch} \end{aligned} \quad (4)$$

The Malmquist productivity index in equation (4) measures productivity change, i.e., total factor productivity (Tfp), which can be decomposed into the product of Techch and Effch, where

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Effch can be decomposed into the decomposition formulas shown in equations (5) and (6), respectively.

$$\text{Tfp} = \text{Technical progress (Techch)} \times \text{Technical efficiency (Effch)} \tag{5}$$

$$\text{Effch} = \text{pure technical efficiency (Pech)} \times \text{scale efficiency (Sech)} \tag{6}$$

The static DEA-CCR mainly evaluates the efficiency of financial inputs and outputs at one point in time, while the dynamic DEA-Malmquist index mainly evaluates the changes in productivity at multiple points in time. The different levels of development in the base period of each province have led to the existence of large differences in the efficiency of inputs and outputs and productivity of various factors, which may lead to a bias in the evaluation results.

3.3. Kernel Density Analysis

Assuming that$x_1, x_2 \cdots x_n$ is an independently and identically distributed sample of n points with probability density function f, then.

$$f_h(x) = \frac{1}{n}\sum_{i=1}^{n} K_h(x - x_i) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x-x_i}{h}\right) \tag{7}$$

k(-) is the kernel function, which meets the following conditions: non-negative, integral of 1, consistent with the probability density property, mean value of 0. Commonly used kernel functions include Gauss, Epanechnikov, Rectangle and other kernel functions.This paper adopts the Epanechnikov kernel function to perform kernel density analysis to estimate the characteristics of the distribution of the efficiency of the green financial industry in the YRD region, in order to improve the efficiency of the green financial industry. financial industry efficiency distribution characteristics, in order to improve the efficiency of data fitting and analyze the dynamic trend of green financial efficiency. The kernel function is as follows.

$$K(x) = \begin{cases} \frac{3}{4}(1 - x^2), & \text{if} |x| \le 1 \\ 0, & \text{otherwise} \end{cases} \tag{8}$$

4. Statistical Coverage, Selection of Indicators and Data Sources

4.1. Statistical Coverage

Research Object. Due to the inconsistency in the statistical caliber of the green finance industry in the Yangtze River Delta region, and the lack of input and output data of related industries, it is difficult to estimate the efficiency of the green finance industry directly. In view of this, the research object of this paper is the four provinces and cities of Zhejiang, Jiangsu, Shanghai and Anhui in the Yangtze River Delta region.

4.2. Selection of Indicators

According to the Guiding Opinions on Building a Green Financial System issued by the People's Bank of China and seven other ministries and commissions on August 31, 2016, green finance refers to financial services provided for environmental protection, energy conservation, clean energy, green transportation, green buildings and other fields in order to support environmental improvement, climate change response, and resource saving and efficient utilization. According to this definition, green finance should cover green credit, green securities, green insurance, green investment, carbon finance and other financial forms.

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Therefore, this paper constructs a more complete indicator system for measuring the green financial efficiency of the Yangtze River Delta.

In this system, the input indicators cover two main aspects. On the one hand, it is labor, where labor input is specifically represented by the number of people employed in the financial sector, which reflects the input of green finance in terms of human resources. On the other hand, there is capital, which is measured by green credit, green bonds, green investment and green insurance.

Output Indicators This paper selects green GDP as a single output indicator. Green GDP integrates resource and environmental factors on the basis of traditional GDP, and is the core indicator in the comprehensive environmental and economic accounting system, which can reflect the actual development level of a region after including the environmental cost of development into the assessment factors.

In summary, the green financial development efficiency measurement index system is obtained, as shown in Table 1.

Table 1. Green finance efficiency evaluation index system

Level 1 indicators	Secondary indicators	Tertiary indicators	Indicator measurement methodology
capital investment	green credit	Interest Expenditures of the Six Major Energy-Consuming Industrial Sectors	Interest Expenditures of the Six Major Energy-Consuming Industrial Sectors/Industrial Interest Expenditures
	green bond	Market capitalization share of environmental protection companies	Total market capitalization of environmental protection companies / Total A-share market capitalization
	green investment	Percentage of fiscal expenditure on energy conservation and environmental protection	Financial expenditure on energy conservation and environmental protection/financial expenditure
	green insurance	Extent of promotion of environmental pollution liability insurance	Environmental pollution liability insurance income/total premium income
labor input	Number of people working in finance	Percentage of people working in finance	Number of financial employees/tertiary employment
Economic output	Green GDP	Green GDP share	Gross Regional Product - Environmental Protection Expenditures

4.3. Data Sources

The research object of this paper is four provinces and cities in the Yangtze River Delta region, and the research period is 2012-2022. The data related to green finance are from China Environmental Statistics Yearbook, China Finance Yearbook, and China Energy Statistics Yearbook; the data on green GDP, human capital, and general fiscal revenue are from Jiangsu Province Statistical Yearbook, Zhejiang Province Statistical Yearbook, Anhui Province Statistical Yearbook, and Shanghai Municipal Statistical Yearbook.

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5. Green Financial Efficiency Measurement, Motivational Decomposition and Evolution in the Yangtze River Delta Region

5.1. Measurement of Green Financial Efficiency in the Yangtze River Delta Region based on Static DEA-CCR Modeling

The panel data of green finance input and output indicators of 4 provinces and cities in the Yangtze River Delta region in 2012-2022 are measured by DEAP2.1 software, and the results are shown in Table 2 below. It can be found that in 2012-2022, most of the integrated efficiency of the 4 provinces and cities in the Yangtze River Delta region is lower than 1, not realizing the DEA effective, and the total efficiency of different provinces in different years varies greatly, showing diversified characteristics, as shown in:

(1) Comprehensive Efficiency (CE), which measures the overall efficiency of green finance. the efficiency of green finance in the four provinces and cities in the Yangtze River Delta region gradually increases from 2012 to 2022. Among them, Jiangsu Province and Shanghai Municipality have higher comprehensive efficiencies, with mean values of 0.798 and 0.743 respectively, which are slightly higher than the overall level. During the period from 2012 to 2022, provinces and municipalities have successively introduced relevant policies to promote the development of green finance. from the perspective of individual provinces and municipalities, Zhejiang Province, after being approved as a pilot zone for green financial reform and innovation in 2017, quickly launched an Action Plan in 2018 and formulated three key checklists to promote the development of green finance.2021 In July 2021, the Shanghai Municipal Government issued the "Shanghai International Financial Center Building "14th Five-Year Plan", which is a comprehensive plan to promote the development of green finance. In July 2021, the Shanghai Municipal Government issued the "14th Five-Year Plan for the Construction of Shanghai International Financial Center", which directly mentions the "basic establishment of the status of the international green financial hub" among the development goals for the construction of Shanghai's international financial center, and dedicates the green finance content among the eight major tasks and measures, and is equipped with a column on the development of green finance. In August 2021, the General Office of Jiangsu Province issued the "14th Five-Year Plan for Financial Development of Jiangsu Province", and devoted a special chapter to the deployment of "vigorously developing green finance and supporting the construction of beautiful Jiangsu".2021 In April 2021, the Anhui Provincial Government issued the "Anhui National Economic and Social Development Plan", and the "Anhui National Economic and Social Development Plan".

(2) Pure Technical Efficiency (PEC), which measures the efficiency of technology application without considering the scale factor. All four provinces reach 1 in terms of pure technical efficiency, indicating that they have all reached a relatively efficient state in terms of technology application. It indicates that all these regions are more mature in the application of green finance-related technologies, and there is no obvious technological waste. The mean value of pure technical efficiency of Jiangsu Province and Shanghai Municipality is 1.0, which indicates that the application of green financial technology in these two regions has reached the optimal state. The mean value of pure technical efficiency of Anhui Province and Zhejiang Province is also very close to 1.0, which is 0.9999 and 0.9991 respectively, indicating that the technical effectiveness of these two regions has reached a high level.

(3) Scale efficiency (SEC), which measures the appropriateness of production scale. The scale efficiency of Anhui Province is similar to the comprehensive efficiency, with a mean value of 0.373, indicating that the scale efficiency has a greater impact on the comprehensive efficiency. The mean value of scale efficiency in Jiangsu Province and Shanghai Municipality is similar to the comprehensive efficiency, with a mean value of 0.798 and 0.743, respectively, indicating that scale efficiency contributes more to the comprehensive efficiency in these two provinces.

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The mean value of scale efficiency in Zhejiang Province is 0.529, which is slightly higher than the comprehensive efficiency, indicating that scale efficiency has a certain positive impact on the comprehensive efficiency in Zhejiang Province.

Table 2. Static Green Finance Efficiency Value of Four Provinces and Cities in Yangtze River Delta Region, 2012-2022

	norm	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	average value
Anhui	CE	0.223	0.250	0.274	0.289	0.319	0.360	0.413	0.447	0.461	0.517	0.548	0.373
	PEC	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999	1.000	1.000	1.000
	SEC	0.223	0.250	0.274	0.289	0.319	0.360	0.413	0.447	0.462	0.517	0.548	0.373
Jiangsu	CE	0.579	0.583	0.667	0.749	0.719	0.829	0.881	0.866	0.900	1.000	1.000	0.798
	PEC	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SEC	0.579	0.583	0.667	0.749	0.719	0.829	0.881	0.866	0.900	1.000	1.000	0.798
Shanghai	CE	0.490	0.533	0.578	0.612	0.678	0.749	0.815	0.857	0.881	0.979	1.000	0.743
	PEC	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SEC	0.490	0.533	0.578	0.612	0.678	0.749	0.815	0.857	0.881	0.979	1.000	0.743
Zhejiang	CE	0.385	0.398	0.409	0.437	0.452	0.504	0.561	0.625	0.620	0.723	0.693	0.528
	PEC	1.000	1.000	0.999	0.999	0.999	0.998	0.998	1.000	0.998	1.000	0.999	0.999
	SEC	0.385	0.398	0.409	0.438	0.453	0.505	0.562	0.625	0.622	0.723	0.694	0.529

5.2. Measurement of Green Financial Efficiency in the Yangtze River Delta Region based on Dynamic DEA-Malmquist Modeling

5.2.1. Dynamic Analysis of Green Financial Efficiency in the Yangtze River Delta Region

In order to further analyze the dynamics of green financial efficiency, the software tool DEAP2.1 was used to calculate the Malmquist index and decomposition of the collected data samples for the period of 2012-2022, and the results are shown in Table 3 below.

Table 3. Malmquist index and decomposition results of green finance in the Yangtze River Delta region, 2012-2022

Particular year	Technical efficiency (EC)	technological progress (TC)	Pure technical efficiency (PEC)	Scale efficiency (SEC)	Total factor productivity (TFP)
2012-2013	0.992	1.070	1.000	0.992	1.061
2013-2014	1.021	1.124	1.000	1.021	1.147
2014-2015	0.969	1.060	0.996	0.972	1.023
2015-2016	0.966	1.130	1.004	0.963	1.090
2016-2017	0.987	1.096	1.000	0.987	1.080
2017-2018	0.986	1.103	1.000	0.985	1.085
2018-2019	0.977	1.097	1.000	0.977	1.070
2019-2020	0.979	1.107	1.001	0.978	1.081
2020-2021	0.982	1.101	1.000	0.982	1.079
2021-2022	0.981	1.102	1.000	0.980	1.079

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From the analysis of the data in Table 3, it can be seen that the dynamic change index of total factor productivity (TFP) of green finance in the Yangtze River Delta region during the period of 2012-2022 all exceeds 1, which indicates that green finance activities have a significant positive impact on the productivity and quality of economic activities. Technical efficiency includes the effects of pure technical efficiency and scale efficiency, and the fluctuation of technical efficiency is mainly affected by scale efficiency in the case that most of the pure technical efficiencies are 1. The technical efficiency (EC) of 1.021 in 2013-2014 is the only one among all the years in which the technical efficiency is greater than 1, which suggests that there is a significant improvement in the efficiency of technology utilization in this period, which may be due to the existence of factors such as technological innovation and management optimization. Pure Technical Efficiency (PEC) in 2014-2015 is) 0.996, which is one of the few cases where it is not 1, indicating that there may be minor problems in technical management in that period, which affects the pure technical efficiency. Meanwhile, total factor productivity is a combination of technical efficiency and technological progress, and when both technical efficiency and technological progress have better performance, total factor productivity can also maintain a better growth trend, such as in 2013-2014.

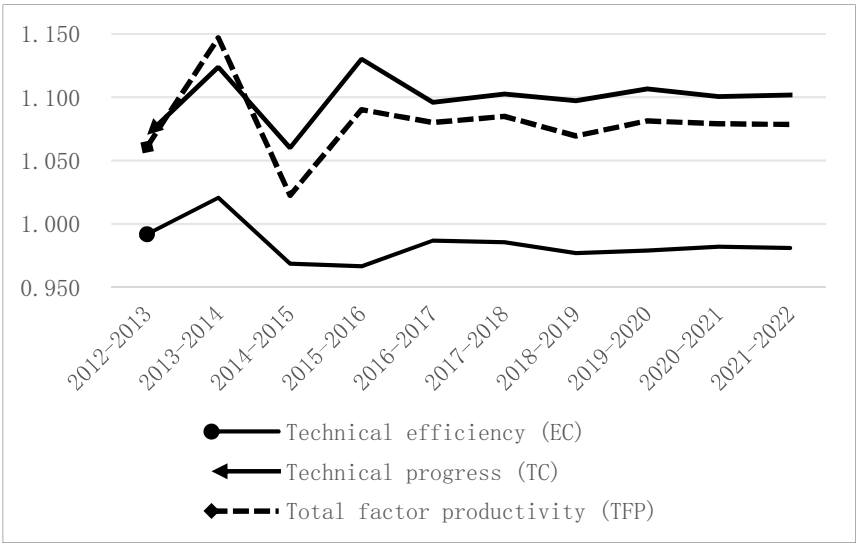

Figure 1. Decomposition results of Malmquist index of green finance in Yangtze River Delta region, 2012-2022

Technical efficiency (EC) reflects the ability of a production unit to transform inputs into outputs under a given level of technology, and the closer its value is to 1, the more fully the technology is utilized and the more rational the allocation of resources is; technological progress (TC) embodies the degree of technological development and improvement over time, and a value greater than 1 indicates technological progress, while a value less than 1 indicates technological regression; and total factor productivity (TFP) comprehensively takes into account a variety of factors such as technological efficiency and technological progress, and is an important indicator for measuring production efficiency, and its growth implies an increase in production efficiency. Total Factor Productivity (TFP) takes into account a variety of factors such as technological efficiency and technological progress, and is an important indicator of production efficiency, and its growth implies the improvement of production efficiency. As can be seen from Figure 1, the dynamic change index of TFP from 2012 to 2022 shows a fluctuating change trend, and the overall trend shows a slow development trend.The results obtained from the decomposition of the Malmquist index find that the dynamic change of technological progress is basically the same as the trend of total factor productivity change, and the change

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index of technological progress has decreased significantly in the period of 2014 and 2016, and total factor productivity has decreased accordingly. Therefore, the consequent decrease proves that the fundamental reason for the gradual increase in regional green finance TFP is technological progress.

5.2.2. Decomposition of Green Financial Efficiency Drivers in the Yangtze River Delta Region

The technical efficiency change index is decomposed into pure technical efficiency and scale efficiency, as shown in Figure 2, the overall performance of the gradual development of the trend, a sharp decline in 2014-2016, but in the second year and then quickly rebounded. The curves of technical efficiency change and scale efficiency change almost overlap, indicating that scale efficiency contributes more to technical efficiency, and scale efficiency is dominant in technical efficiency.

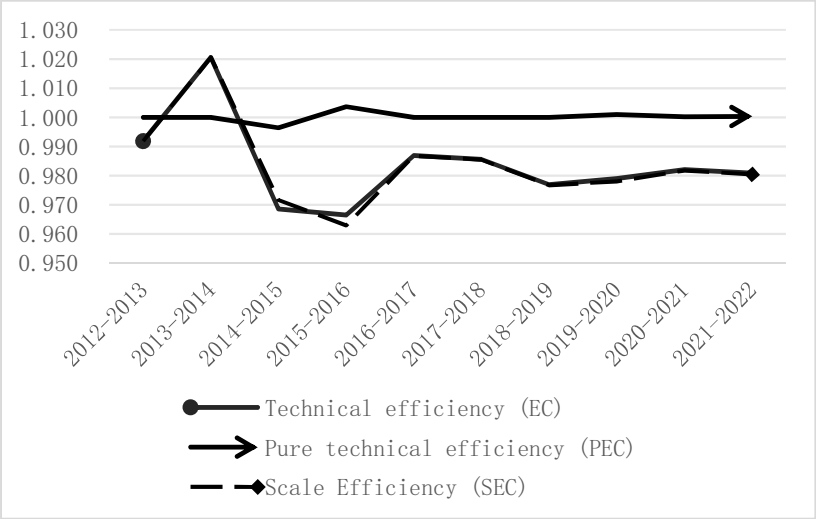

Figure 2. Decomposition results of the index of change in green financial technical efficiency in the Yangtze River Delta region, 2012-2022

In order to further study the regional differences in green financial efficiency in the Yangtze River Delta region, the calculation was organized to obtain the green financial Malmquist index and decomposition results of the four provinces and cities in the Yangtze River Delta region, as shown in Figure 2, Technical efficiency is a combination of pure technical efficiency and scale efficiency. When the pure technical efficiency stabilizes around 1, the fluctuation of technical efficiency is mainly affected by scale efficiency. Technical efficiency has a clear rise from 2012 - 2013 to 2013 - 2014, followed by a fluctuating downward trend, leveling off after 2017 - 2018. Pure technical efficiency basically stabilized at 1 in the rest of the years except for 2012 - 2013 when it was slightly lower than 1, indicating that pure technical efficiency has maintained a good level in the long term, and the technical and managerial capabilities of production units are relatively stable. The pure technical efficiency in 2012-2013 is slightly lower than 1, which may be due to the fact that there are some minor problems in the production unit's technological application or management during that period, affecting the play of pure technical efficiency, but the pure technical efficiency in subsequent years has been improved, and the pure technical efficiency has been improved. efficiency, but it was improved in the following years.

From the total factor productivity change indexes of the four provinces and cities in the YRD region in Table 4, total factor productivity is the product of technical efficiency and technical progress; Anhui Province has higher technical efficiency and technical progress, so it has the

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highest total factor productivity. The technical efficiency and technical progress of each province and city interact with each other and together determine the total factor productivity. The total factor productivity change indices of the four provinces and cities are all greater than 1. Among them, Anhui Province has the highest growth rate of 13.395%, and its main contributing factor is technological progress. Shanghai has the lowest total factor productivity growth rate, and its technical efficiency and technical progress efficiency are also at a low level, indicating that Shanghai has efficiency bottlenecks in some parts of the production process, which need to be further optimized. Anhui Province has the highest technical efficiency of 1.028, Zhejiang Province and Shanghai Municipality are lower, respectively 0.972 and 0.978, Jiangsu Province is 1.000, indicating that Anhui Province is relatively good in the utilization of existing technology and resource allocation, while Zhejiang and Shanghai are mainly lower scale efficiency pulling down the overall technical efficiency.

Table 4. Green finance Malmquist index and decomposition results of four provinces and cities in Yangtze River Delta region, 2012-2022

Province	Technical efficiency (EC)	Technical progress (TC)	Pure technical efficiency (PEC)	Scale Efficiency (SEC)	Total factor productivity (TFP)
Anhui	1.028	1.104	1.000	1.028	1.134
Jiangsu Province	1.000	1.094	1.000	1.000	1.094
Shanghai	0.978	1.094	0.990	0.988	1.069
Zhejiang Province	0.972	1.115	1.000	0.972	1.084

Note: The data in the table are averages for 2012-2022.

5.3. Evolution of Green Financial Efficiency in the Yangtze River Delta

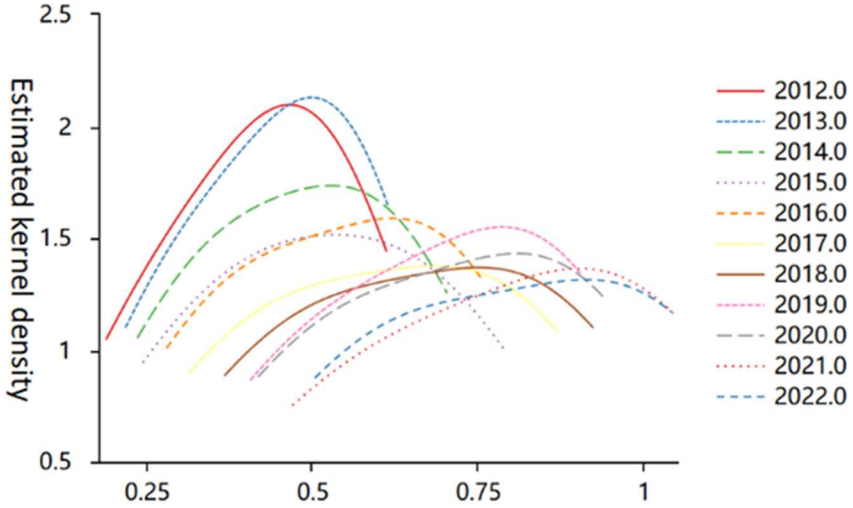

Figure 3. Kernel Density of Green Financial Efficiency in the Yangtze River Delta Region, 2012-2022

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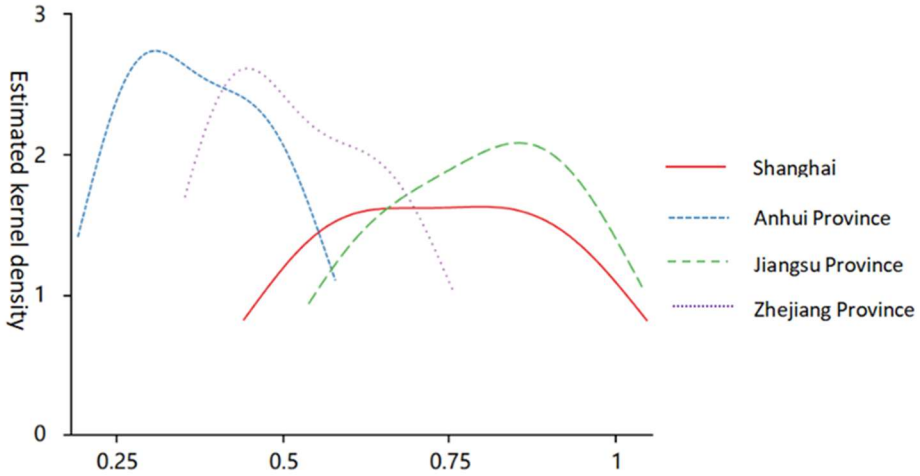

Figure 4. Kernel Density of Green Financial Efficiency in Four Provinces and Cities in the Yangtze River Delta Region

The distributional characteristics of the evolution of green financial efficiency in the Yangtze River Delta region are estimated using the kernel density estimation method. In order to improve the precision of the estimation, the bandwidth is fixed in this paper in the estimation of time years, and the adaptive kernel density estimation method is used to obtain the green financial efficiency value estimated by time in Fig. 1. And in Figure 2, the Epanechnikov kernel function is used, the MISE optimization principle is adopted for the selection of bandwidth, the bandwidth of Epanechnikov kernel function is not fixed, and the adaptive kernel density estimation method is also adopted to obtain the green financial efficiency value estimated by province. As can be seen in Fig. 4, the green financial efficiency values are higher in 2012 and 2013, mostly distributed around 0.5, and the peaks later on have a clear tendency to move to the right, and in general, the green financial efficiency values of the Yangtze River Delta in 2012-2022 show a relative decrease in the stability. This indicates that green finance in the Yangtze River Delta region has experienced a start-up period, a rapid development period, and a stable development period from 2012 to 2022, while the decreasing probability density peak value of green financial efficiency also indicates that the green financial efficiency of the Yangtze River Delta region has a growing trend in the sample period, but it is not significant, and the green financial efficiency is relatively stable in most of the years.

6. Conclusion and Recommendations

In this paper, the static DEA-CCR model and the dynamic Malmquist model were used to measure, decompose and evolve the green financial efficiency of some provinces and municipalities in the Yangtze River Delta region from 2012 to 2022, and the study found that:

First, the green financial efficiency of the four provinces and cities in the Yangtze River Delta region gradually rises from 2012 to 2022, with the comprehensive efficiency of Jiangsu Province and Shanghai City occupying a higher position, the rapid development of Zhejiang Province driven by policies, the scale efficiency of Anhui Province having a greater impact on the comprehensive efficiency, and the pure technological efficiency of the four provinces and cities reaching a higher level, indicating that the application of technology is relatively mature. At the same time, the dynamic change index of TFP during this period is over 1, and the change trend of technical progress index and TFP is highly consistent, which highlights the key role of technological innovation capacity in enhancing total factor productivity, indicating that technological progress is the core driving force to promote the improvement of green financial efficiency in the Yangtze River Delta region. The kernel density analysis shows that the green

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financial efficiency value of the Yangtze River Delta is generally stable and has a growth trend, with different performances in different provinces and cities, including Anhui Province, which has significant growth efficiency, Shanghai City, which has steady growth and a large magnitude, and Jiangsu and Zhejiang Provinces, which have also shown steady progress, reflecting the different development modes and speeds in the region.

Second, green financial policies have a significant impact on regional efficiency, especially in the Yangtze River Delta region, which has promoted the rapid development of green finance in Zhejiang Province, reflecting the differences in the effects of policy implementation in different regions, and that the precise implementation of policies and the adjustment of policies according to local conditions are crucial to the development of regional green finance. The level of financial market development has an important impact on the efficiency of green finance, and the development of stock and bond markets plays a positive role, but market volatility has a negative impact, indicating that a stable and healthy development of the financial market is an important guarantee for the enhancement of the efficiency of green finance. The management ability and innovation consciousness of financial institutions affect green financial efficiency, and the green technological innovation of enterprises is positively correlated with it and there are regional differences in the industry, which emphasizes the necessity of building the capacity of financial institutions themselves and driving innovation to improve green financial efficiency.

Third, Shanghai's comprehensive green financial efficiency is leading, with Jiangsu, Zhejiang and Anhui provinces in decreasing order, with obvious differences between regions, reflecting that regional synergy and balanced allocation of resources for green financial development in the Yangtze River Delta region need to be strengthened. Although the green financial efficiency of Anhui Province is low, the efficiency of Shanghai is also higher when the economy develops well, reflecting the positive driving force of economic development on green finance, and revealing the relationship between the regional economy and green finance that promotes each other. 2012-2022 Total Factor Productivity (TFP) in the Yangtze River Delta region mainly comes from technological progress, with the technological progress index rising and the technological efficiency index slightly decreasing, which clarifies the dominant role of technological innovation in the promotion of green financial development. The dominant position of technological innovation in promoting the development of green finance is clarified.

Based on the findings of this study, the following policy recommendations are given:

First, optimize the allocation of resources and regional synergistic development of the Yangtze River Delta region should strengthen the green financial cooperation between provinces and municipalities, the lower reaches of the Yangtze River Economic Belt to drive the middle and upper reaches of the Yangtze River, and optimize the allocation of financial resources through regional synergistic development, such as the establishment of a regional platform for green financial cooperation to share experience and resources to achieve common development. Formulate development strategies according to local conditions. Each region should formulate practical strategies based on its own green finance development situation, with developed regions enhancing the depth of services, and less developed regions broadening the breadth of services and strengthening the construction of technologies and infrastructures, so as to realize the balanced and efficient development of green finance in the region.

Secondly, to improve the policy and market environment, the government can formulate policies to improve green finance, balancing macro-control and market mechanism, avoiding excessive intervention, such as through tax incentives, financial subsidies and other policies to guide the flow of funds to the green industry, and at the same time, strengthen the synergy and stability of the policy, in order to create a good policy environment for the development of green finance. At the same time, promote the transformation and upgrading of industrial structure to cultivate emerging green industries and broaden the demand for financial services, optimize the structure of the financial market to improve the utilization rate of financial assets,

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strengthen the supervision and improve the infrastructure, enhance the vitality and stability of the market, and promote the benign interaction between green finance and the real economy.

Thirdly, to promote technological innovation and application, enterprises should take high-tech innovation as the core of continuous investment in R&D resources to enhance the contribution of technology level to industrial efficiency, such as the use of big data, blockchain and other technologies to improve the efficiency of risk management and resource allocation in the field of green finance in innovative financial products and services. In addition, the Yangtze River Delta region should actively introduce cutting-edge technologies and successful experiences at home and abroad, for example, some provinces and cities in the Yangtze River Economic Belt can introduce innovative models of green finance to promote the development of their own green finance, narrow the gap with developed regions, and enhance the overall competitiveness of green finance.

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