

# Research on the Measurement of Gold Green Total Factor Productivity in the Yangtze River Economic Belt under the Background of Green Finance

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## Abstract

With the continuous growth of the economy, the contradiction between finance and the environment has become increasingly prominent, and green finance has attracted much attention due to its sustainable development function. This study integrates green financial efficiency into green total factor productivity based on the two-stage super efficiency unexpected SBM model, and constructs the financial green total factor productivity of the Yangtze River Economic Belt from 2013 to 2021. The convergence model is used to verify the convergence of productivity development. The research results indicate that, in terms of time dimension, the efficiency of green finance in the Yangtze River Economic Belt is relatively stable, the level of financial ecological performance first decreases and then increases, and the financial feedback ecological performance remains at a high level for a long time. The overall trend of financial green total factors is increasing, and financial green technology innovation is an important driving factor for the increase; In terms of convergence testing, no significant alpha convergence was found in the upper, middle, and lower reaches of the Yangtze River Economic Belt, and the regional differences did not significantly decrease. However, there was overall beta convergence, indicating a "catch-up effect" from low productivity provinces to high productivity provinces.

## Keywords

Green Finance; Green Total Factor Productivity; SBM Model; Convergence Model.

## 1. Introduction

With rapid economic growth and worsening environmental degradation, sustainable development has become a common goal of the international community. In this context, green finance, as an important tool to support environmental improvement and sustainable economic growth, has received widespread attention. It guides capital towards green projects, supports the research and application of low-carbon technologies, and promotes economic green transformation. In China, with the high emphasis on ecological civilization construction, the development of green finance has ushered in great opportunities. As one of China's economic belts, the Yangtze River Economic Belt carries the dual tasks of regional economic development and ecological environment protection. Therefore, measuring the financial green total factor productivity (FGTFP) of the Yangtze River Economic Belt and evaluating its regional differences is of great significance for understanding the relationship between regional financial ecological performance (FEP) and economic growth, and promoting regional green development.

This study explores the measurement methods and regional differences of FGTFP in the context of green finance in the Yangtze River Economic Belt. By constructing a two-stage SBM model and integrating GFE into the measurement of green total factor productivity, this study

conducts an in-depth analysis of the FGTFP changes in the Yangtze River Economic Belt from 2013 to 2021, and uses a convergence model to test the convergence of productivity development in various regions. This study aims to provide scientific basis and policy recommendations for promoting green economic growth and ecological civilization construction in the Yangtze River Economic Belt through in-depth research on green finance and FGTFP. This study will be conducted through literature review, research methods and variable selection, empirical analysis and results, spatial spillover effects and convergence testing, and summary and recommendations.

## 2. Research Methods and Variable Selection

### 2.1. Research Methods

#### 2.1.1. Super Efficiency Unexpected SBM Model

Super efficient unexpected SBM incorporates relaxation variables into the objective function to solve the problem of variable relaxation, while decomposing effective units with an efficiency value of 1 to achieve comparison between effective units and improve the accuracy of the results. At the same time, introduce the issue of unexpected output and compare and rank each evaluation unit.

Assuming  $n$  evaluation units, for the  $r$ -th evaluation unit, there are  $m$  input indicators,  $p$  expected outputs, and  $q$  unexpected outputs. The corresponding inputs ( $X_r$ ), expected outputs ( $Y_r$ ), and unexpected outputs ( $Z_r$ ) are:

$$X_r = (x_{1r}, x_{2r}, \dots, x_{ir}, \dots, x_{mr})^T \tag{1}$$

$$Y_r = (y_{1r}, y_{2r}, \dots, y_{jr}, \dots, y_{pr})^T \tag{2}$$

$$Z_r = (z_{1r}, z_{2r}, \dots, z_{kr}, \dots, z_{qr})^T \tag{3}$$

In the formula:  $x_{ir}$  represents the  $i$ -th input indicator of the  $r$ -th evaluation unit,  $y_{jr}$  represents the  $j$ -th expected output indicator of the  $r$ -th evaluation unit, and  $z_{kr}$  represents the  $k$ -th unexpected output indicator of the  $r$ -th evaluation unit. To evaluate the green finance of the  $r$ -th province in the Yangtze River Economic Belt, the super efficient SBM model is as follows:

$$e = \min \frac{1 + \frac{1}{m} \sum_{i=1}^m \left( \frac{s_i^-}{x_{ir}} \right)}{1 - \frac{1}{p+q} \left( \sum_{j=1}^p \frac{s_j^+}{y_{jr}} + \sum_{k=1}^q \frac{s_k^-}{z_{kr}} \right)} \tag{4}$$

$$s.t. \left\{ \begin{array}{l} \sum_{u=1, \neq r}^n x_{ir} \lambda_u - s_i^- \leq x_{ir} \\ \sum_{u=1, \neq r}^n y_{jr} \lambda_u + s_j^+ \geq y_{jr} \\ \sum_{u=1, \neq r}^n z_{kr} \lambda_u - s_k^- \leq z_{kr} \\ 1 - \frac{1}{p+q} \left( \sum_{r=1}^p \frac{s_r^+}{y_{rk}^d} + \sum_{t=1}^q \frac{s_t^{u-}}{y_{tk}^u} \right) > 0 \\ \lambda_u, s_i^-, s_j^+, s_k^- \geq 0 \end{array} \right. \quad (5)$$

In the formula, e is the relative efficiency value,  $s_i^-, s_j^+, s_k^-$  correspond to the slack variables of input, expected output, and unexpected output, respectively. m, p, and q correspond to the number of inputs, expected output, and unexpected output, respectively. u is the evaluation unit (u=1,2,... n), and is the weight of input-output indicators. If  $e \geq 1$ , the input-output efficiency of the corresponding evaluation unit is effective. The larger e, the higher the efficiency of the evaluation unit and the higher the resource utilization rate. If  $e < 1$ , the input-output efficiency of the corresponding evaluation unit is low, and the province has not achieved technical or efficiency effectiveness.

### 2.1.2. Malmquist Index Decomposition

The Malmquist index is commonly used to measure production efficiency over time and analyze the impact of technological efficiency and innovation on efficiency during a certain period. Under this framework, the Malmquist index can be applied to the construction of FGTFP in this study, which consists of Financial Green Technology Progress (FGTC) and Financial Green Efficiency Change (FGEC):

$$FGTFP_{t+1} = FGEC \times FGTC \quad (6)$$

$$FGTFP(x_t, y_t, x_{t+1}, y_{t+1}) = \left[ \frac{e_t(x_{t+1}, y_{t+1})}{e_t(x_t, y_t)} \times \frac{e_{t+1}(x_{t+1}, y_{t+1})}{e_{t+1}(x_t, y_t)} \right]^{\frac{1}{2}} \quad (7)$$

$$FGEC = \frac{e_{t+1}(x_{t+1}, y_{t+1})}{e_t(x_t, y_t)} \quad (8)$$

$$FGTC = \left[ \frac{e_t(x_{t+1}, y_{t+1})}{e_{t+1}(x_{t+1}, y_{t+1})} \times \frac{e_t(x_t, y_t)}{e_{t+1}(x_t, y_t)} \right]^{\frac{1}{2}} \quad (9)$$

In the formula,  $e_t(x_t, y_t)$ ,  $e_t(x_{t+1}, y_{t+1})$ ,  $e_{t+1}(x_t, y_t)$ ,  $e_{t+1}(x_{t+1}, y_{t+1})$  the four efficiency values are calculated by the SBM model. FGTFP is higher than 1, it indicates a significant increase in FEP.

### 2.1.3. Convergence Model

The convergence model is used to study whether regions with different levels of development have the same development trend. Due to various factors, the level of regional development is uneven. If regions with lower development levels can move towards higher development levels at a higher speed, they will have a certain degree of convergence.

For convergence issues, this study uses common alpha and beta convergence methods [6]. Alpha convergence refers to the process in which the deviation of a certain indicator between different regions tends to decrease over time, while beta convergence refers to whether regions with lower initial economic levels have a higher growth rate than regions with higher economic levels. According to research needs, this study chooses absolute  $\beta$  convergence to detect whether there is a "catch-up effect" in FGTFP in different regions. The  $\beta$  convergence of this study follows Yang Chen's definition [7] as follows:

$$\frac{1}{T} \ln \left( \frac{FGTFP_{i,t}}{FGTFP_{i,0}} \right) = \beta_0 + \beta \ln(FGTFP_{i,0}) + \varepsilon \tag{10}$$

In the formula:  $FGTFP_{i,0}$  represents the FGTFP of the  $i$ -th province base period,  $FGTFP_{i,t}$  represents the FGTFP at the end of the  $i$ -th province,  $T$  represents the time span,  $\beta_0$  is a constant term,  $\beta$  is the convergence coefficient, and  $\varepsilon$  is the random error.

## 2.2. Variable Selection

### 2.2.1. Investment Indicators

For the first stage SBM model, green credit, green investment, green insurance, and green bonds are used as inputs. For the two-stage SBM model, the construction of green total factor productivity is relatively fixed, generally considering labor, resources, and capital. This study measures FGTFP using the number of employed people as the labor input factor, total energy consumption as the resource input factor, and capital stock as the capital input factor. The GFE obtained from the first stage SBM is used as the green finance element in this study.

### 2.2.2. Expected Output Indicators

For the one-stage SBM model, according to Cui et al.'s research literature [8], this study adds green patents as the expected output on the basis of GDP. For the two-stage SBM model, the expected output of GTFP is economic output, so this study chooses GDP as the expected output.

### 2.2.3. Unexpected Output Indicators

**Table 1.** Input Output Indicators

Phase I SBM (GFE)			Phase II SBM (FGTFP)		
Level 1 indicators	Level 2 indicators	Level 3 indicators	Level 1 indicators	Level 2 indicators	Level 3 indicators
Input	Green credit	Total credit for environmental protection projects	Input	Labor force	Employment
	Green investment	Investment in environmental pollution control		Capital	Capital stock
	Green insurance	Revenue from environmental pollution liability insurance		Resources	Total energy consumption
	Green bond	Total Green Bond Issuance		Green finance	Green finance efficiency
Expected outputs	Economic output	GDP	Expected outputs	Economic output	GDP
	Green patent	Green invention patent authorization	Undesired output	Carbon emissions	Total carbon emissions
		Green utility model patent authorization			
Undesired output	Environmental pollution	Weighted industrial wastewater, solid waste, etc	--	--	--

For the one-stage SBM model, Cui et al. constructed an environmental pollution index using entropy weight method for factors such as industrial wastewater discharge [8]. This study draws on this approach and constructs an environmental pollution index using the entropy weight method. For the two-stage SBM model, the unexpected output of this study is the total carbon emissions.

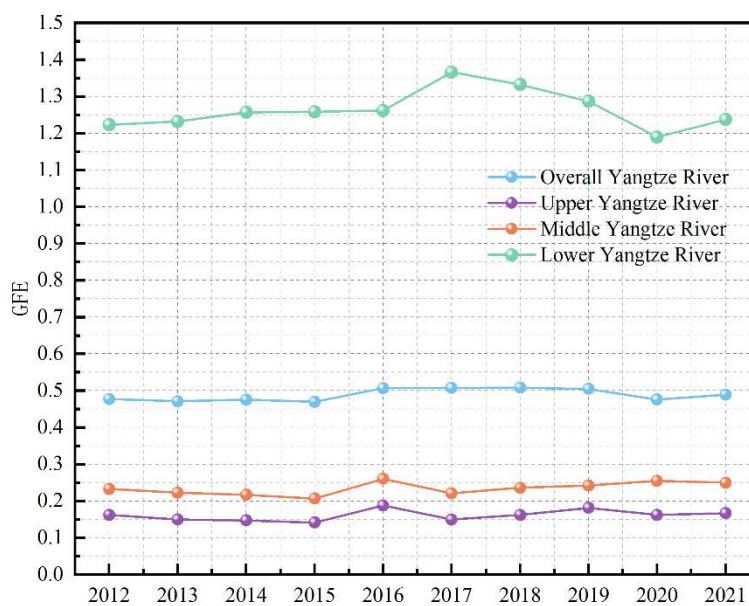
### 2.3. Data Sources

The GFE and FGTFP measurement samples in this study are from 11 provinces in the Yangtze River Economic Belt, including upstream regions such as Sichuan, Chongqing, Guizhou, and Yunnan, midstream regions such as Anhui, Hubei, Hunan, and Jiangxi, and downstream regions such as Jiangsu, Zhejiang, and Shanghai. The research period is from 2012 to 2021, and the indicator data is sourced from various provincial (municipal, district) statistical yearbooks such as the China Statistical Yearbook, the National Bureau of Statistics, and the EPS database.

## 3. Empirical Analysis and Results

### 3.1. Measurement and Analysis of Green Financial Efficiency in the Yangtze River Economic Belt

#### 3.1.1. Global Analysis of Green Finance Efficiency



**Figure 1.** GFE of the Yangtze River Economic Belt Region from 2012 to 2021

According to the one-stage SBM model, obtain the GFE of the Yangtze River Economic Belt from 2012 to 2021. Figure 1 shows that overall, the GFE of the Yangtze River Economic Belt has experienced slight fluctuations, showing a trend of first slowly rising, then slightly falling, and then rebounding. It first reached a clear peak in 2016 and then showed a significant decline in 2020. For different regions, the GFE in the lower reaches of the Yangtze River Economic Belt has always remained at a high level, reaching its peak in 2017, indicating the maturity of the downstream region in the field of green finance. From 2019 to 2021, the GFE in the downstream region has declined, but it is still higher than that in the upstream and midstream regions. The overall GFE in the upper reaches of the Yangtze River Economic Belt is the lowest, showing a significant improvement in 2016, but failing to maintain a high growth trend. The GFE performance in the midstream region is relatively stable, indicating the gradual deepening and development of green finance in the midstream region.

### 3.1.2. Partial Analysis of Green Finance Efficiency

Table 2 reveals the GFE of each province in the Yangtze River Economic Belt. The study found that Jiangsu Province ranked first with an average of 1.397, indicating its leading position in the field of green finance, which is closely related to its level of economic development and high emphasis on green finance projects. Shanghai and Zhejiang Province followed closely behind with average values of 1.343 and 1.053, respectively. The GFE in the lower reaches of the Yangtze River Economic Belt is generally higher than that in the upper and middle reaches. In the upstream and midstream provinces, Sichuan Province and Hubei Province performed relatively well, with an average of 0.302 and 0.298, indicating that the upstream and midstream regions are gradually developing in the field of green finance. Guizhou Province and Yunnan Province rank lower, with an average of 0.068 and 0.106, respectively. This result may be related to factors such as the regional economic development level, financial market maturity, and green finance policies, indicating that there are challenges in promoting and applying green finance in the southwestern region. There are significant regional differences in GFE among provinces in the Yangtze River Economic Belt, emphasizing the important role of factors such as economic development level, regional policy support, and market demand in the development of green finance. This analysis provides data support for formulating regional and differentiated strategies to promote green finance.

**Table 2.** 2012-2021 GFE of various provinces in the Yangtze River Economic Belt

Year	JS	SH	ZJ	SC	HB	AH	HN	CQ	JX	YN	GZ
2012	1.328	1.298	1.043	0.325	0.312	0.261	0.254	0.174	0.104	0.095	0.053
2013	1.362	1.276	1.057	0.290	0.275	0.249	0.273	0.149	0.093	0.105	0.056
2014	1.429	1.297	1.045	0.308	0.264	0.228	0.274	0.125	0.101	0.092	0.065
2015	1.372	1.330	1.072	0.251	0.271	0.242	0.234	0.156	0.081	0.091	0.067
2016	1.340	1.318	1.127	0.341	0.332	0.293	0.302	0.211	0.114	0.119	0.078
2017	1.584	1.481	1.032	0.273	0.293	0.257	0.231	0.174	0.102	0.085	0.066
2018	1.554	1.416	1.027	0.327	0.310	0.255	0.246	0.141	0.133	0.106	0.075
2019	1.430	1.425	1.005	0.328	0.313	0.278	0.251	0.188	0.126	0.127	0.082
2020	1.239	1.212	1.117	0.290	0.312	0.305	0.251	0.166	0.150	0.119	0.072
2021	1.331	1.378	1.003	0.285	0.299	0.313	0.244	0.195	0.143	0.120	0.069
Mean	1.397	1.343	1.053	0.302	0.298	0.268	0.256	0.168	0.115	0.106	0.068
Rank	1	2	3	4	5	6	7	8	9	10	11

## 3.2. Measurement and Analysis of Financial Green Total Factor Productivity in the Yangtze River Economic Belt

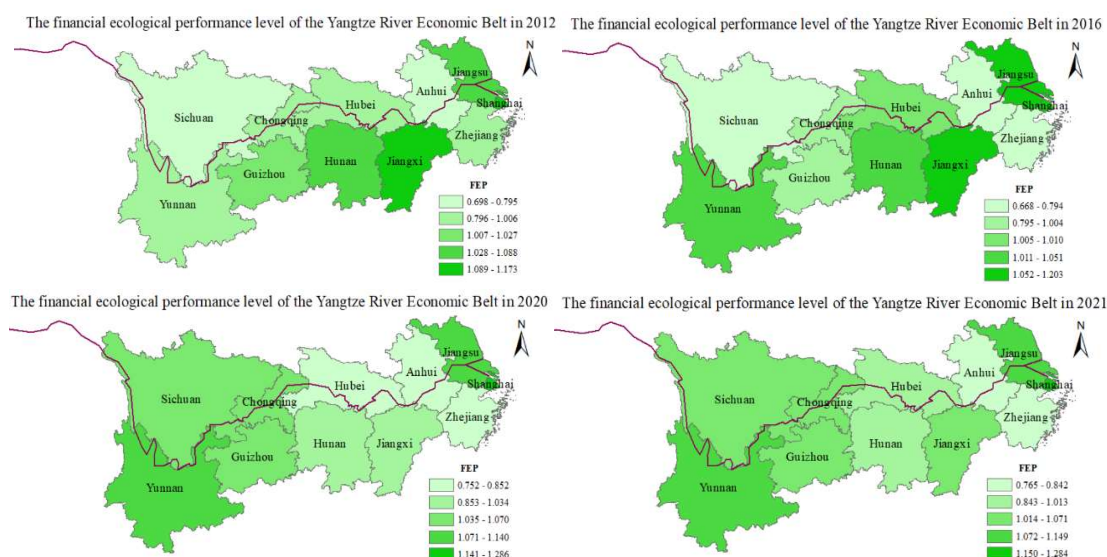
### 3.2.1. Overall Analysis of FEP in Financial Ecological Performance

According to the two-stage SBM model, we obtained the FEP of the Yangtze River Economic Belt as shown in Table 3, which shows an overall trend of improvement. Among them, the GFE of Shanghai, Jiangsu, and Jiangxi is higher than 1.100, leading other provinces in the Yangtze River Economic Belt, indicating that their green finance development has the best feedback effect on ecological protection. Shanghai and Jiangsu both come from the lower reaches of the Yangtze River. In contrast, although Zhejiang occupies an important position in terms of economic output and industrial layout, it ranks third in terms of GFE, while the average FEP is 0.814, ranking tenth. This indicates that Zhejiang's investment in GFE has not achieved ideal ecological protection effects, and there are certain challenges to the effectiveness of green finance. The FEP in provinces such as Anhui and Guizhou is relatively low, indicating that these regions still have significant room for improvement in promoting the harmonious development of finance and ecological environment.

**Table 3.** FEP of the Yangtze River Economic Belt from 2012 to 2021

Year	SH	JS	JX	YN	HN	CQ	HB	GZ	SC	ZJ	AH
2012	1.173	1.088	1.165	1.003	1.06	1.001	1.005	1.027	0.795	1.006	0.698
2013	1.117	1.115	1.192	1.055	1.045	1.016	1.02	1.012	0.864	0.824	0.715
2014	1.142	1.122	1.144	1.089	1.045	1.037	1.022	1.008	0.828	0.817	0.755
2015	1.167	1.125	1.173	1.023	1.053	1.022	1.015	0.655	0.867	0.791	0.691
2016	1.203	1.135	1.143	1.051	1.041	1	1.01	1.004	0.794	0.776	0.668
2017	1.214	1.136	1.088	1.108	1.046	1.028	1.013	1.028	0.966	0.798	0.749
2018	1.226	1.122	1.058	1.067	1.044	1.043	1.021	1.049	1.005	0.798	0.779
2019	1.287	1.102	1.072	1.12	1.007	0.752	1.045	1.011	1.012	0.817	1
2020	1.286	1.138	1.016	1.14	1.034	1.07	0.851	1.066	1.054	0.752	0.852
2021	1.284	1.117	1.04	1.149	1.013	1.043	1.01	1.071	1.049	0.765	0.842
Mean	1.21	1.12	1.109	1.08	1.039	1.001	1.001	0.993	0.923	0.814	0.775
Rank	1	2	3	4	5	6	7	8	9	10	11

From the perspective of time evolution, the FEP of the Yangtze River Economic Belt as a whole presents a "U" shape, with a trend of first decreasing and then increasing, and continues to rise from 2017 to 2021. Combined with the background of 2017, the government began to build a green finance reform and innovation pilot zone, indicating that this plan has promoted the application of green finance in ecological protection and sustainability. And the FEP in the downstream areas of the Yangtze River Economic Belt is relatively stable, while the FEP in the upstream areas is gradually increasing. In 2020, the FEP in the upstream areas successfully surpassed that in the downstream areas and maintained this trend in 2021. Figure 2 shows the initial, transitional, and final states of FEP. Research shows that the overall trend of upstream FEP is upward, while the trend of midstream FEP is downward, and the downstream changes are not significant.



**Figure 2.** FEP of the Yangtze River Economic Belt in the Initial, Transitional, and Final Stages

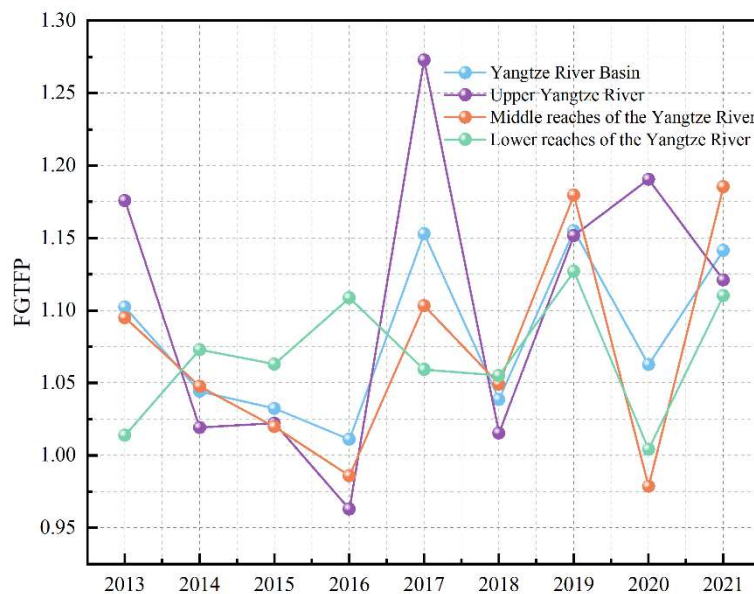
### 3.2.2. Global Analysis of Financial Green Total Factor Productivity

To reflect the input-output ratio of GFE and observe whether FEP has growth potential, this study uses Malmquist index decomposition to obtain measurement results of FGTFP, financial green efficiency change FGEC, and financial green technology innovation FGTC.

**Table 4.** Malmquist Index Decomposition of the Yangtze River Economic Belt from 2012 to 2021

Year	FGTFP	FGEC	FGTC
2012-2013	1.102	0.999	1.106
2013-2014	1.044	1.004	1.040
2014-2015	1.032	0.960	1.091
2015-2016	1.011	1.036	0.992
2016-2017	1.153	1.040	1.109
2017-2018	1.039	1.005	1.033
2018-2019	1.155	1.008	1.155
2019-2020	1.063	1.012	1.053
2020-2021	1.141	1.014	1.126
Mean	1.082	1.009	1.078

Table 4 reveals the changes in the FGTFP, FGEC, and FGTC indices of the Yangtze River Economic Belt. The overall FGTFP of the Yangtze River Economic Belt showed an increasing trend year by year from 2012 to 2021, with an average of 1.082, indicating a positive overall development of FGTFP. Especially during the periods of 2016-2017 and 2018-2019, the growth of FGTFP was significant, which was found to be related to the significant improvement of FGTC and also positively influenced by FGEC, indicating that technological progress and efficiency improvement jointly promoted the growth of FGTFP. The overall FGEC remained at 1.009, reflecting a certain degree of stability and slight growth in FEP of the Yangtze River Economic Belt in terms of green efficiency. The mean of FGTC is 1.078, indicating that technological innovation and improvement have provided important support for the growth of FGTFP.

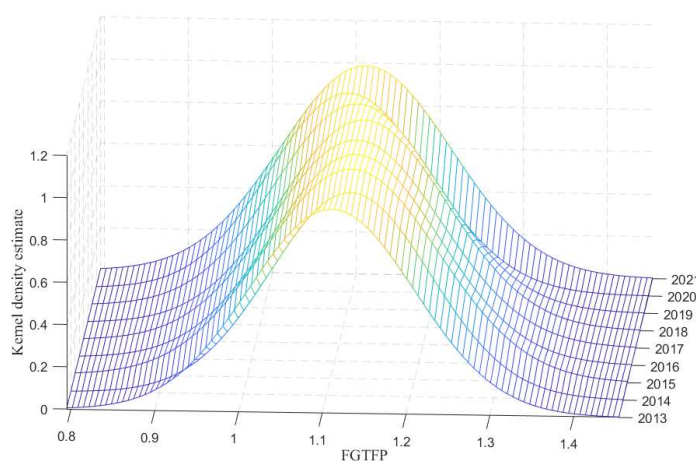


**Figure 3.** FGTFP Trends in the Yangtze River Economic Belt Region

Further subdivide the upper, middle, and lower reaches of the Yangtze River Economic Belt to demonstrate the differences in green total factor productivity between different regions. The study found that the average FGTFP in the upstream region is 1.104, which performs the best and reflects the progress in production efficiency and environmental protection capacity in the upstream region. The FGTFP in the midstream and downstream regions are 1.072 and 1.068,

respectively. In 2016-2017 and 2018-2019, the FGTFP of all regions in the Yangtze River Economic Belt significantly increased.

This study used kernel density estimation as shown in Figure 4 to reveal the evolution trend of FGTFP, and found that over time, the distribution of FGTFP showed a significant rightward bias. During the study period, the FGTFP index was mainly concentrated around 1.1, indicating that FGTFP experienced significant improvement and enhancement during this period. Over time, the rightward shift in distribution reflects an overall increase in FEP, indicating that the financial industry has made substantial progress in promoting environmental protection and efficient resource utilization. The central trend of FGTFP does not show non-linear growth, but rather presents an improvement that accumulates year by year.



**Figure 4.** Kernel density estimation of FGTFP

**3.2.3. Partial Analysis of Financial Green Total Factor Productivity**

**Table 5.** FGTFP of the Yangtze River Economic Belt from 2013 to 2021

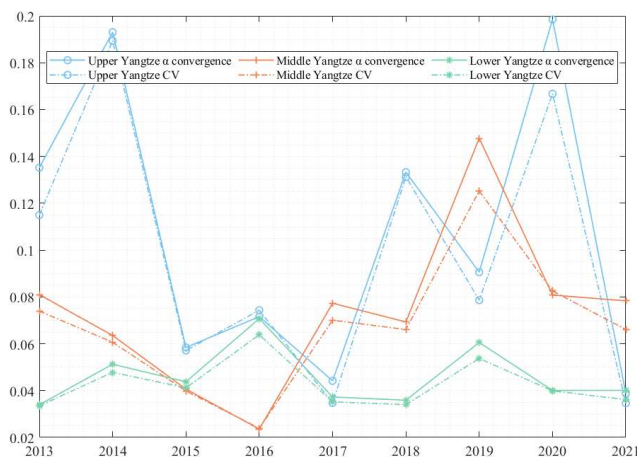
Year	CQ	AH	HB	ZJ	YN	SH	SC	GZ	JX	JS	HN
2013	1.335	1.105	1.196	1.033	1.207	0.975	1.153	1.009	1.078	1.034	1
2014	1.261	1.093	1.111	1.107	1.049	1.098	0.971	0.795	0.987	1.014	0.999
2015	1.014	0.982	1.013	1.103	0.959	1.069	1.1	1.016	1.077	1.016	1.008
2016	1.001	1.011	1	1.162	1.015	1.136	0.858	0.978	0.961	1.028	0.972
2017	1.272	1.178	1.161	1.094	1.213	1.063	1.288	1.318	1.048	1.02	1.026
2018	1.197	1.093	1.122	1.08	0.959	1.072	1.021	0.884	0.977	1.014	1.005
2019	1.027	1.389	1.166	1.139	1.235	1.181	1.148	1.197	1.114	1.061	1.05
2020	1.454	0.968	0.897	0.96	1.027	1.016	1.048	1.234	0.96	1.037	1.09
2021	1.101	1.162	1.3	1.156	1.122	1.082	1.086	1.175	1.159	1.092	1.121
Mean	1.185	1.109	1.107	1.093	1.087	1.077	1.075	1.067	1.04	1.035	1.03
Rank	1	2	3	4	5	6	7	8	9	10	11

Table 5 reveals the FGTFP index of various provinces in the Yangtze River Economic Belt, with Chongqing ranking first with an average of 1.185. In 2020, the FGTFP was 1.454, indicating significant progress in FEP for that year. In 2014, the lowest FGTFP in Guizhou Province was 0.795, indicating the challenges it faces in transitioning to a green economy. The differences in FGTFP among provinces highlight the imbalance in promoting the efficiency and effectiveness of green finance investment. The average FGTFP of each province is higher than 1, revealing the progress and growth potential of FEP in the Yangtze River Economic Belt.

### 3.3. Convergence Analysis of Financial Green Total Factor Productivity in Various Provinces

#### 3.3.1. Region Convergence based on Alpha Convergence Test

In the previous section, the measurement, differences, and spatial spillover effects of FGTFP have been studied, and FGTFP can reflect the improvement of FEP in terms of technology or efficiency. If  $FGTFP > 1$ , it is considered that FEP is showing an increasing trend. Based on current research, there are certain differences in FGTFP. This study uses alpha convergence to test whether regional FGTFP changes with time and determine whether it will tend to a horizontal state. To verify the robustness of the results, this paper uses coefficient of variation (CV) to measure the relative inter provincial differences in FGTFP. The obtained results are shown in Figure 5. If the alpha convergence in the following year is smaller than that in the previous year over time, it indicates the existence of alpha convergence, otherwise it indicates divergence.



**Figure 5.** Convergence of FGTFP in the upper, middle and lower reaches of the Yangtze River Economic Belt

Figure 5 shows the changes in FGTFP in the upstream, midstream, and downstream regions of the Yangtze River Economic Belt. In the development trend of FGTFP in the three regions of the Yangtze River Economic Belt, the alpha convergence value in the upstream region fluctuates greatly between different years, with the highest value reaching 0.198 and the lowest value being 0.039. This indicates that the convergence of FGTFP in upstream regions varies at different times. Overall, the high-value alpha convergence index indicates that the FEP growth potential in the region is relatively large, and there is a trend of rapidly narrowing the gap with other regions. The range of alpha convergence values in the midstream region is from 0.024 to 0.148, indicating that the midstream region is relatively stable compared to the upstream region in the growth and catch-up process of FGTFP. According to CV, the dispersion of FGTFP in the middle reaches is relatively low, and the FGTFP between provinces in the middle reaches is relatively close, with small regional differences. The overall convergence value of alpha in downstream areas is the lowest, with the highest value being only 0.071 and the lowest value being 0.034. This reflects that although FEP is relatively developed in downstream areas, its growth rate is slow and the regional differences are small. CV also reflects that the FGTFP gap in this region is relatively small and stable.

In some years, such as 2014-2015 in the upper reaches of the Yangtze River Economic Belt, alpha convergence was achieved, indicating that these years were accompanied by the diffusion

and spillover of financial ecological technology progress, and its FGTFP developed rapidly. From 2017 to 2020, there was an overall trend of divergence, while from 2020 to 2021, there was a trend of convergence. In 2021, green finance has been maturely applied, forming a stable development trend. FGTFP has a convergence trend, and the development gap of FGTFP in various provinces is gradually decreasing.

### 3.3.2. Testing the "Catch-up effect" of the Yangtze River Economic Belt based on $\beta$ convergence

In order to verify whether there is a "catch-up effect" from low FGTFP provinces to high FGTFP provinces in the development of the Yangtze River Economic Belt, this study calculated the absolute  $\beta$  convergence of FGTFP in the Yangtze River Economic Belt based on equation (24), and the results are as follows:

$$\frac{1}{T} \ln \left( \frac{FGTFP_{i,t}}{FGTFP_{i,0}} \right) = 0.014 - 0.103 \ln(GFTFP_{i,0}) + \varepsilon \quad (11)$$

The coefficient of the constant term in this equation is 0.014, and the  $\beta$  convergence coefficient is -0.103. This study set the artificial significance level of  $\alpha$  to 0.05, and first constructed a t-test null hypothesis  $H_0$ : the  $\beta$  coefficient is equal to 0, that is, there is no  $\beta$  convergence between FGTFPs. Alternative hypothesis  $H_1$ : If the  $\beta$  coefficient is less than 0, it indicates the existence of  $\beta$  convergence; if it is greater than 0, it indicates the absence of  $\beta$  convergence. The t-statistic of the  $\beta$  coefficient is -5.192. According to the critical value of the t-statistic, the significance  $p=0.001 < \alpha$  at this point can reject the null hypothesis  $H_0$  and choose the alternative hypothesis  $H_1$ . The  $\beta$  coefficient is -0.103, indicating that there is  $\beta$  convergence in FGTFP among provinces in the Yangtze River Economic Belt, that is, there is a "catch-up effect". The  $R^2$  of the equation is 0.750, and adjusting  $R^2$  to 0.722 indicates a good fitting effect.

Based on this result, we can conclude that low FGTFP provinces are catching up with high FGTFP provinces and have  $\beta$  convergence. This means that through appropriate policy intervention and resource allocation, the balanced development of FEP can be promoted, thereby driving the overall improvement of the regional economy.

### 3.4. Robustness Analysis

In this study, the analysis results of alpha convergence and coefficient of variation (CV) showed that there were numerical differences between the two, but the volatility was the same. This discovery indicates that the model in this study has a certain degree of robustness and can effectively support the conclusions of this research.

## 4. Conclusion and Suggestions

### 4.1. Conclusion

This study is based on a two-stage SBM model, which first constructs GFE and then FEP. Through Malmquist index decomposition, FGTFP is constructed, revealing that both GFE and FEP have a good development trend while building FGTFP. The study found that financial technology innovation is the main driving factor for the increase of FGTFP. In addition, the alpha convergence of the Yangtze River Economic Belt is not significant, but there is beta convergence, and low productivity areas are catching up with high productivity areas, showing a positive development trend.

## 4.2. Suggestions

Based on the conclusions and actual situation, this study proposes the following suggestions: (1) increase the support for green finance, promote financial technology innovation to achieve long-term regional green development; (2) Properly intervene in resource allocation, promote balanced development of regional FEP, and reduce regional disparities; (3) Real time detection and prediction of FGTFP to adjust strategies in a timely manner.

## Acknowledgments

This work is supported by Anhui University of Finance and Economics College Student Innovation and Entrepreneurship Training Program Project (Grant No: 202410378227).

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