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Measurement of Agricultural Total Factor Productivity and Autocorrelation Analysis under the Goal of Emission Reduction and Carbon Sink Increase

--A Case Study of Prefecture-level Cities in the Yangtze River Delta

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Abstract

The Yangtze River Delta region occupies an important position in the overall construction of rural agricultural modernization in China. In order to better promote the green and high-quality development of agriculture in this region, this paper creatively incorporates the element of emission reduction and carbon sink increase into the framework of agricultural Total Factor Productivity (TFP) index system, based on panel data of prefecture-level cities in the Yangtze River Delta from 2011 to 2020. The agricultural Green Total Factor Productivity (GTFP) is then calculated using the SBM-ML model, and the spatial econometric model is employed to analyze the main factors influencing its variation. The research reveals that: (1) The overall trend of agricultural GTFP in the Yangtze River Delta region shows an upward trend, mainly driven by the level of agricultural green technological progress; (2) There is a significant regional difference in agricultural GTFP; (3) The development of agricultural GTFP exhibits a "face-point-face" structure, where regions with higher agricultural GTFP will drive neighboring lower regions to collectively improve. Based on these findings, the paper proposes optimizing the path of agricultural total factor productivity to promote the improvement of GTFP and advance the coordinated development of agricultural green regions.

Keywords

Yangtze River Delta region; Total factor productivity; Emission reduction and carbon sink increase; Spatial spillover effects.

1. Introduction

With the escalating global climate change, reducing greenhouse gas emissions and increasing carbon sequestration have become crucial issues for global green development. Agriculture, as a significant sector for reducing greenhouse gas emissions and storing carbon sinks, has become an important research area for achieving emission reduction and carbon sink increase goals through improving agricultural total factor productivity (TFP) and increasing carbon sink storage. On March 31, 2023, the "2023 China Agricultural and Rural Low-Carbon Development Report" was released in Beijing. The report pointed out that the focus of agricultural development in China is to ensure stable supply of key agricultural products and food security.

China's agricultural carbon emissions are mainly survival-oriented and basic, and under the policy of low-carbon production in agriculture, China's agricultural carbon emissions intensity is relatively low. At the same time, the report analyzed the current problems and challenges facing China's agricultural and rural low-carbon development and proposed a series of solutions. It is expected that by implementing these measures, the improvement of agricultural green total factor productivity (GTFP) will be promoted, thus driving the sustainable development of agriculture.

Achieving carbon peaking and carbon neutrality requires addressing agricultural carbon emissions, making the study of agricultural GTFP development in green agriculture and understanding its level of green development particularly important. As an important region for agricultural production in China, the Yangtze River Delta region is a typical economically developed area and also one of the sensitive regions to global climate change. Therefore, studying the emission reduction and carbon sink potential of agriculture in prefecture-level cities in the Yangtze River Delta region not only provides scientific basis for agricultural production in this area but also offers important references for agricultural emission reduction and carbon sink increase nationwide.

2. Literature Review

Currently, enhancing agricultural GTFP is a primary research focus in the field of agricultural development.

2.1. Methodological Approaches for Studying Agricultural Total Factor Productivity

In terms of measurement methods, most scholars primarily employ methods such as stochastic frontier analysis[1], Solow residual method, data envelopment analysis, and algebraic index method. A minority also utilize parametric estimation methods, constructing stochastic frontier production function models for calculating agricultural GTFP, which, compared to parametric estimation methods, non-parametric estimation has the advantage of not requiring function settings and has no constraints on constant returns to scale, making it suitable for cases with numerous output and input quantities. Therefore, the DEA-ML method is commonly used to measure agricultural productivity through non-parametric methods. Long Shaobo et al. used the DEA-ML model to calculate the growth rates of agricultural TFP in high-quality development and traditional agriculture in China, comparing the two[2]. Lv Na et al. used the SBM-ML index to measure China's agricultural green total factor productivity, finding that when environmental factors are taken into account, agricultural productivity is higher than ordinary productivity[3].

2.2. Selection of Agricultural Total Factor Productivity Indicator System

In studying agricultural TFP, besides differences in measurement methods, there are also differences in the constructed indicator systems, especially for calculating non-expected outputs. Xiao Qin et al. measured non-expected outputs using agricultural production carbon emissions, calculating the total carbon emissions including methane emissions from paddy fields, animal intestinal fermentation and feces, and agricultural materials[4]. Li Jianxuan et al. defined non-expected outputs as pollutants from non-point sources such as total nitrogen, total chemical oxygen demand, and total phosphorus[5]. Ma Guoqun et al. considered both as non-expected outputs when calculating agricultural green total factor productivity[6]. Meng Xianghai and other scholars included many factors such as crops and livestock in their analysis and derived an analytical method based on nitrogen surplus intensity of agricultural land[7].

2.3. Factors Affecting Agricultural Total Factor Productivity

In the study of agricultural GTFP influencing factors, Huang Weihua et al. studied wheat agricultural green total factor productivity from the perspective of environmental regulation and spatial spillover effects, finding that technological innovation is influenced by environmental regulations, and neighboring areas can use environmental regulations to promote wheat production efficiency[8]. Chen Fang et al. explored the impact of agricultural product import and export trade levels on agricultural GTFP, which showed a significant positive effect[9]. Li Xiaolong et al. verified that agricultural GTFP is influenced by agricultural product trade from the perspective of rural financial development, proposing that both imports and exports of trade contribute to improving agricultural GTFP[10]. Li Jianxuan et al. calculated that rural financial development scale, structure, and efficiency all have a positive impact on agricultural green TFP, but their mechanisms differ significantly[5]. Gao Yang et al. investigated the impact of agricultural informatization on agricultural GTFP, finding a positive linear relationship between the improvement of agricultural GTFP and the level of agricultural informatization[11]. Wu Chuanqing and Song Ziyi believe that the level of mechanization and the improvement of rural human capital stock have a significant promoting effect on agricultural green productivity[12].

2.4. Study of Regional Differences in Agricultural Total Factor Productivity

Due to differences in agricultural production environments, policies, and resource conditions in different regions, researchers have also focused on the differences and influencing factors of agricultural green total factor productivity at the national, regional, provincial, and other levels. Li Bo and Hu Baoyun used the SBM-GML index method to measure the GTFP of the Yellow River Basin and its decomposition items, finding that from 2001 to 2019, the GTFP of agriculture in the Yellow River Basin showed an overall upward trend, with agricultural technological progress driving the growth of GTFP, and there were significant differences in the growth patterns of GTFP among provinces[13]. Zhao Yanli and Dang Guoying found that the average annual growth rate of agricultural productivity in counties in Anhui Province was 5.31%, driven by the promotion of agricultural green technology, but there were also inhibiting factors. Urbanization has a inverted "U" relationship with agricultural productivity, and different factors have different effects on different regions[14]. Tu Weiliang and Lou Junting determined the core factors affecting the growth of agricultural green total factor productivity in Hubei Province through the measurement of agricultural green total factor productivity and the establishment of fixed effects models[15]. It was found that under the background of "dual carbon" targets, the growth of agricultural green total factor productivity in Hubei Province is influenced by core factors such as the level of mechanization and the increase in value-added of high-tech industries, and its regional spatial distribution is uneven and fluctuates. Feng Ying and Liu Fan analyzed the impact of crop planting structure on agricultural GTFP in Shaanxi Province under the dual carbon targets, and analyzed other potential factors. The study found that scientifically planning crop planting categories is conducive to reducing agricultural carbon emissions and improving agricultural GTFP, which is crucial for promoting high-quality development of agriculture and rural revitalization[16].

In summary, most existing literature focuses on the study of agricultural TFP and its influencing factors, providing rich research results for this paper. However, domestic research on agricultural GTFP is relatively late, mainly focusing on the national level, with fewer studies at the regional level, especially in the Yangtze River Delta region. There are differences in natural resources, economic development levels, and agricultural modernization levels among regions in China, so expanding research samples and scope, conducting regional studies, comprehensively understanding the current situation and influencing factors of agricultural green total factor productivity, and providing more accurate and scientific guidance for promoting agricultural sustainable development and protecting the ecological environment are of great practical significance. Therefore, based on previous research, this paper will study agricultural total factor productivity and its spatial spillover effects starting from the Yangtze River Delta region.

3. Index Selection and Data Sources

3.1. Index Selection

3.1.1. Input Variables

Based on previous research, this paper primarily selects labor force, sown area, fertilizer, pesticides, agricultural film, total mechanical power, and irrigated area as input variables.

Table1. Calculaton Indicators for Input Variables

Indicator Name	Indicator Description	Unit
Labor Force	Number of employees engaged in agriculture, forestry, animal husbandry, and fishery industries*(Agricultural total output value / Total output value of agriculture, forestry, animal husbandry, and fishery)	10,000 people
Sown Area	Area under cultivation of crops	10^3 hm^2
Fertilizer	Amount of fertilizer applied	10,000 tons
Pesticides	Amount of pesticides used	10,000 tons
Agricultural Film	Amount of agricultural film used	10,000 tons
Total Mechanical Power	Total mechanical power in agriculture	10^4 kW·h
Irrigated Area	Effective irrigated area	10^3 hm^2
Livestock	Number of large livestock at the end of the year	10,000 heads

3.1.2. Output Variables

(1) Expected Output. The expected output is primarily set as the total agricultural output value (in 100 million yuan). In this regard, the paper mainly utilizes the resident price consumer index to deflate the values in the statistical yearbook to eliminate the impact of price changes on output values.

(2) Non-Expected Output. Non-expected output is mainly represented by the total carbon emissions, including emissions from machinery, irrigation, fertilizers, pesticides, agricultural film, and livestock. First, based on the research of Duan Aihua et al., a conversion formula for carbon emissions from machinery is constructed:

$$E_m = A_m \times B + W_m \times C$$

Where, A_m represents the total agricultural planting area, W_m represents the total agricultural mechanical power, B and C are carbon emission conversion coefficients. Then, based on the carbon emission calculation formula used by Li Bo et al., the carbon emissions of agricultural input variables other than machinery are calculated. The formulas for carbon emissions from fertilizers, pesticides, and agricultural film are similar to the machinery carbon emission formula, with the main formula being:

$$N = \sum N_i = \sum Q_i \times S_i$$

Where, N represents agricultural carbon emissions, N_i represents the total carbon emissions of the ith element, Q_i represents the content of the ith element, and S_i represents its carbon emission coefficient. The carbon emission coefficients for the corresponding carbon sources are as follows:

3.2. Data Sources

Table 2. Carbon Emission Coefficients for Major Carbon Sources

Carbon Source	Carbon Emission Coefficient
Machinery	B = 16.47 kg/hm^2, C = 0.18 kg/kW
Irrigation	266.48 kg/hm^2
Fertilizer	0.8956 kg/kg
Pesticides	4.9341 kg/kg
Agricultural Film	5.18 kg/kg
Pig	5 kg/head
Cow	61.33 kg/head
Sheep	6.16 kg/head

Based on the current situation of domestic statistical data, this paper selects data from prefecture-level cities in the Yangtze River Delta region from 2011 to 2020. The data sources include "China Rural Statistical Yearbook,""China Statistical Yearbook,""China Agricultural Statistical Data,""China Environmental Statistical Yearbook," and the statistical bureaus of various prefecture-level cities. Interpolation is used to fill in a very small number of missing values, and the relevant carbon emission coefficients mainly refer to the IPCC (2006).

4. Measurement Results and Data Analysis

This paper uses Stata software to calculate the SBM model for the data and obtains the agricultural green total factor productivity of 41 cities in the Yangtze River Delta. Through methods such as classification and summary, the agricultural green total factor productivity of the Yangtze River Delta region from 2011 to 2020 is analyzed, revealing its overall trend and regional differences.

4.1. Overall Trend of Agricultural Green Total Factor Productivity (GTFP) in the Yangtze River Delta Region

Utilizing the SBM model, the agricultural GTFP, GTPC, and GTEC of the Yangtze River Delta region were calculated, and line charts were plotted based on the calculated averages. From the charts, it can be observed that from 2011 to 2020, both the GTFP and GTPC values of the Yangtze River Delta region were consistently above 1. According to the definition, when both values exceed 1, it indicates an upward trend in agricultural development. This suggests that the comprehensive production efficiency and green agricultural level of the Yangtze River Delta region have been continuously improving during the study period. However, as agricultural development in the region progresses further, the GTFP and GTPC values gradually approach 1, indicating a transition from a period of rapid growth to stable development in agricultural productivity and green agriculture level.

Meanwhile, the index of agricultural green technology efficiency in the Yangtze River Delta region showed a general trend of "initial fluctuations, mid-term stability, and rapid growth in the later stage." Research indicates that from 2011 to 2014, influenced by the uncertain global financial situation, China's socioeconomic environment was generally poor, and environmental governance was in its early stages, with its effects not yet significant. Although breakthroughs were made in green agricultural technology, the comprehensive implementation of new technologies still required time, resulting in fluctuating GTEC values during this period. However, in 2015, China enacted the "Environmental Protection Law," strengthening environmental regulation, while the economic development in the Yangtze River Delta region gradually recovered. Therefore, agricultural green production efficiency changed relatively smoothly during this period. It was not until 2017 that environmental taxes began to be implemented nationwide, with some trading pilots established in the Yangtze River Delta region. Due to the preparatory work in the previous period, the index of green technology efficiency in the region showed a rapid growth trend. After 2019, the level of green agriculture in the Yangtze River Delta region was relatively high, and technological levels approached world-class standards, resulting in a slowdown in growth, requiring breakthroughs through independent research and development to overcome bottlenecks.

Overall, through the implementation of a model of mutual restraint and coordinated development between the environment and the economy, the Yangtze River Delta region has achieved better development in its agriculture and the entire economic system.

4.2. Decomposition of Agricultural Green Total Factor Productivity (GTFP) Index in Various Provinces of the Yangtze River Delta

With a total of 41 prefecture-level cities in the Yangtze River Delta region, mainly comprising Shanghai, Zhejiang Province, Jiangsu Province, and Anhui Province, this paper directly divides the 41 prefecture-level cities in the Yangtze River Delta region using the method of the three provinces and one city to obtain the average values for each region and draw bar charts.

By dividing the indices of the Yangtze River Delta region from 2011 to 2020 according to the three provinces and one city and the overall method, it can be seen that except for Anhui Province, the GTFP of other provinces and cities in the region are higher than the average level of the Yangtze River Delta. Among them, Shanghai has the highest index, reaching 1.201, while Anhui Province has the lowest index at 1.068, indicating that the GTFP level of various provinces and cities in the Yangtze River Delta region is relatively high, and the overall development level is steadily increasing. At the same time, the index of agricultural green technology efficiency in each region is approximately equal to 1, indicating that the green technology efficiency level in each region is relatively stable. In future work, this factor can be considered to improve the level of technical efficiency in emission reduction and increase carbon sequestration, thereby enhancing agricultural GTFP.

Shanghai has been positively influenced by its high economic level and technological advancement far surpassing other cities. Additionally, due to its vigorous development of the strategy of science and technology leading agriculture, while protecting the environment, it has effectively improved its level of green technological progress. In terms of scientific and technological advancement, it has made significant contributions to the agricultural green production efficiency in the Yangtze River Delta region. It can be seen that the GTPC of each region is greater than 1, indicating that the national strategy for agricultural scientific and technological innovation has been effectively implemented in the Yangtze River Delta region, essentially achieving a new situation where science and technology drive the economy and the economy and the environment develop together.

4.3. Regional Disparities in Agricultural Green Total Factor Productivity (GTFP) in the Yangtze River Delta

To gain a more detailed understanding of the changes in agricultural GTFP in various regions of the Yangtze River Delta, this study directly used Stata software to calculate the values of each city in the Yangtze River Delta for each year and compared the data to determine the regional differences in agricultural GTFP in the region. The factors influencing these differences were analyzed to achieve better development.

During the period from 2011 to 2020, only the average values of Lianyungang City, Suqian City, and Suzhou City were less than 1, with values of 0.995, 0.996, and 0.998, respectively. The average values of other cities were all greater than 1, indicating that during this period, the agricultural GTFP of the Yangtze River Delta region generally showed a good upward trend, consistent with the conclusions mentioned earlier. Additionally, Nanjing City, Wenzhou City, Jinhua City, Ningbo City, and Wuxi City showed strong GTFP values, ranging from 1.204 to 1.320. However, these values exhibited a fluctuating trend, indicating that these areas are significantly affected by environmental constraints. This also suggests that the Yangtze River Delta region has formed a mutually beneficial model of environmental and economic development, which is consistent with the previous analysis. Therefore, while promoting the economy, more attention should be paid to the efficiency of agricultural green development.

4.4. Spatial Autocorrelation Analysis of Agricultural Green Total Factor Productivity (GTFP) in the Yangtze River Delta

Based on the calculated results mentioned earlier, this study used ArcGIS software to process the GTFP index of each prefecture-level city in the Yangtze River Delta region, calculated their global Moran's I index, and systematically analyzed the overall spatial pattern and the evolution of agricultural GTFP in the region to visualize the spatial data. Here, cross-sectional data for each prefecture-level city from 2011 to 2012, 2015 to 2016, and 2019 to 2020 were selected, and a spatial autocorrelation evolution distribution map was drawn.

The table below presents the results of the global Moran's I index calculation for agricultural GTFP in the Yangtze River Delta region.

Table 3. Moran's Ifor agricultural GTFP in the Yangtze River Delta region

	2012	2016	2020	Average
P-value	0.002599	0.097724	0.074188	0.055655
Z-value	3.011611	1.655988	1.785451	1.913727
Moran's I	0.254799	0.079143	0.127926	0.144247

According to the table, the global Moran's I index indicates that the agricultural GTFP of the Yangtze River Delta region generally has a positive value, which is significant at a 10% significance level, rejecting the null hypothesis. Therefore, it can be inferred that there is a clustering effect in the high and low levels of agricultural GTFP in the Yangtze River Delta region. The positive values of the global Moran's I index indicate a positive correlation among prefecture-level cities, indicating a strong spatial correlation and spatial clustering of agricultural output among the 41 cities in the Yangtze River Delta region.

Areas with high agricultural GTFP are transitioning from clustered to dispersed development, and areas with high agricultural GTFP continue to spread outward, transforming from dispersion to large-scale aggregation.

Meanwhile, agricultural GTFP in the Yangtze River Delta region is generally increasing, especially in Shanghai, which not only has a superior geographical location but also advanced technology. In 2019, the Yangtze River Delta region established relevant organizations for the production and processing of green agricultural products in Shanghai. Secondly, some areas in Jiangsu and Zhejiang are located in the central part of the Taihu Plain, which has favorable geographical conditions for the development of green agriculture. Therefore, there is an obvious upward trend in the Jiangsu-Zhejiang region in Figure 3. Influenced by the integrated development of the Yangtze River Delta region, Anhui Province initially had low agricultural GTFP and low modernization levels, but it showed a rapid growth trend later, indicating a high level of development in agricultural green technological progress in the Yangtze River Delta region.

In summary, except for certain environmental improvements with some delay factors, regions with high agricultural GTFP have a certain diffusion effect. These regions can drive the agricultural green productivity of surrounding cities while ensuring their own high production efficiency. The reason for this phenomenon may not only be the requirement of regional integration in the Yangtze River Delta region but also the diffusion of advanced green production technologies from the Yangtze River Delta region to the surrounding areas. In the long run, by continuously strengthen regional cooperation, enhancing the circulation of agricultural green scientific and technological resources and means of production, and combining their own advantages to develop new types of high-quality green agriculture, green agriculture in the Yangtze River Delta region and even in the entire country can achieve efficient development.

5. Conclusion and Policy Recommendations

5.1. Conclusion

Based on the SBM-ML index, this study calculated the agricultural GTFP of 41 prefecture-level cities in the Yangtze River Delta from 2011 to 2020 and decomposed this index to comprehensively analyze the agricultural green total factor productivity in the region. The following conclusions can be drawn:

(1) Overall Performance of GTFP: The GTFP in the Yangtze River Delta region shows a generally increasing trend. The main reason for the steady growth of agricultural green total factor productivity in the region is its advanced technology, where the progress in agricultural green technology plays a dominant role, while the efficiency level has a relatively minor impact. However, as the region has achieved a high level of technological advancement over the years, the demand for independent research and development has been increasing annually. In the current social situation, the Yangtze River Delta region is significantly constrained by the environment. Therefore, in the later stage, it should consider enhancing its intrinsic growth potential and improving the current model of improving production efficiency.

(2) Regional Disparities in GTFP: Regional disparities in GTFP in the Yangtze River Delta region are significant. After dividing the agricultural green total factor productivity of various prefecture-level cities into four provinces and one city, it was found that Shanghai has the highest agricultural green total factor productivity, followed by Jiangsu and Zhejiang provinces, with Anhui province having the lowest. Shanghai's GTPC level is significantly higher than that of other provinces and cities. However, the differences between Zhejiang, Jiangsu, and Anhui provinces are relatively small. Shanghai still ranks first in agricultural green total factor productivity in the study of the four provinces and one city. This could be attributed to Shanghai's economic development and significant financial support for agricultural technology development. The level of mechanization is also much higher than in other cities, providing favorable conditions for the development of green agriculture. Conversely, Anhui's cities rank lower. Hence, it is suggested to increase financial support for agricultural green development and actively improve the level of agricultural green technological progress.

(3) Development Pattern of GTFP: The development of GTFP in the Yangtze River Delta region exhibits a "face-point-face" structure. From the ArcGIS spatial pattern evolution map, it can be seen that areas with high agricultural green total factor productivity influence the surrounding areas with lower productivity and help them improve collectively. Cities with high agricultural GTFP are mainly located near the Taihu Plain. Therefore, it can be inferred that the agricultural green total factor productivity in the Yangtze River Delta region is affected by environmental factors. In the future, efforts should be made to strengthen environmental governance and promote high-quality development of agriculture with green environments.

5.2. Policy Recommendations

(1) Promoting Technological Progress: Enhance technology efficiency output by promoting technological progress from imitation to independent innovation. Strengthen cooperation between agricultural bases and research institutions to improve agricultural output per unit area and achieve green development. Tailor technological resource allocation according to the

actual conditions of different regions to promote the improvement of the technology progress index.

(2) Adhering to Regional Integration Policies: Implement the integration strategy of the Yangtze River Delta region, integrate and share the resource advantages of various regions, and promote coordinated development. Leverage the advanced industrial and technological advantages of Shanghai to lead the green development of agriculture in surrounding areas. Strengthen talent exchange and cooperation between regions and establish mechanisms for talent introduction and training to improve the overall regional talent quality. Strengthen the connection of the industrial chain between regions to promote coordinated development and enhance the economic competitiveness and comprehensive strength of the entire region.

(3) Strengthening Environmental Governance: Continuously strengthen environmental protection and regulate and punish behaviors that damage the ecological environment. Focus on improving the ecological efficiency of agriculture to achieve green and healthy development, leading the green development and promoting the high-quality development of agricultural economy. Additionally, protect agricultural land and water resources, promote organic agriculture, and reduce pollution from chemical products to improve the quality and safety of agricultural products. Implement regional coordinated development and ecological protection mechanisms to promote comprehensive, efficient, and green agricultural production. Explore the development path of green agriculture that suits China's national conditions, implement the National Agricultural Green Development Plan during the 14th Five-Year Plan period, and build a green agricultural production system to improve emission reduction and increase efficiency, creating a green and high-quality development of agriculture.

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