Study on Estimation of Agricultural Total Factor Productivity under Carbon Emission Constraints

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Abstract: The estimation of the traditional agricultural total factor productivity rarely balanced resource and environmental constraints. It neglect the negative effect of agricultural economic development on resources and environment. In this paper, the carbon emission constraint is included in the estimation system of agricultural total factor productivity, and the DEA-Malmquist efficiency index with expected and non-expected output is constructed. The empirical analysis of the 11 differences and trends of total factor productivity and decomposition index of agriculture between 2005 and 2014. The results showed that the technological progress under the constraint of carbon emission plays an important role in the growth of agricultural total factor productivity in Jiangxi Province, and technological progress has become the core driving force. In terms of regional conditions, there are some differences in the total factor productivity of agriculture in 11 districts of Jiangxi Province under the constraint of carbon emission. Some of them are located in the state of discordance development of agricultural production and resources.

1. Introduction

The growth of agricultural economy depends on the improvement of agricultural productivity. The total factor productivity of agriculture is a measure of the productivity index that can be used to measure the total agricultural output. It can promote the agricultural competitiveness. However, most of the evaluation of the agricultural total factor productivity is only taking the factors such as capital, labor and land into account, and rarely coordinate the resources and environment constraints that are closely related to agricultural sustainable development, ignoring the negative effects of agricultural economic development on resources and environment, which leads to that part of our country one-sided pursuit of "high input, high consumption, high output" the traditional extensive development model. Agriculture as the basic industry of Jiangxi Province, the regional agricultural production efficiency is different, so quantitative analysis of Jiangxi provincial regional total factor productivity level of agriculture under the carbon emissions constraint conditions, to provide relevant basis the for the development of differentiated agricultural carbon emission reduction policy, the transformation of agricultural economic growth and the protection of the ecological environment will undoubtedly have important theoretical and practical significance.

2. Research Methods

In the process of agricultural production, investing some productivity factors such as capital and labor force, in addition to obtain the expected output of crops, excessive and improper application of fertilizer, pesticides and other means of production materials will inevitably produce carbon emissions and other undesirable output. From total factor perspective, agricultural production should increase the expected output as much as possible, while minimizing undesirable outputs. At present, in the many methods of estimating the total factor, the DEA-Malmquist method based on data envelopment analysis is widely used in various fields.

The Malmquist exponential method is proposed based on data envelopment analysis (DEA), which uses the ratio of the distance function to calculate the input-output efficiency, and can use the

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panel data to calculate the index of total factor productivity change (TFP), technological progress, technical efficiency change and scale efficiency change.

Assuming that s is the base period, the t- total factor productivity change index based on production direction (Malmquist index) is defined as M_{ST}:

$$M_{ST}=\left[\frac{D_i^{\,s}\left(x^t,y^t\right)}{D_i^{\,s}\left(x^s,y^s\right)}\times\frac{D_i^{\,t}\left(x^t,y^t\right)}{D_i^{\,t}\left(x^s,y^s\right)}\right]^{1/2}=\frac{D_i^{\,t}(x^t,y^t)}{D_i^{\,s}(x^s,y^s)}\times\left[\frac{D_i^{\,s}\left(x^t,y^t\right)}{D_i^{\,t}\left(x^t,y^t\right)}\times\frac{D_i^{\,s}\left(x^s,y^s\right)}{D_i^{\,t}\left(x^s,y^s\right)}\right]^{1/2} \tag{1}$$

The Malmquist index can be decomposed into a technical efficiency change index (Effch) and a technological change change index (Techch) under the assumption that the scale of remuneration is constant

$$\text{MST} = \text{Effch}\times\text{Techch} \tag{2}$$

$$\text{Where: Effch} = \frac{D_i^{\,t}(x^t,y^t)}{D_i^{\,s}(x^s,y^s)} \tag{3}$$

Represents the relative technical efficiency change index that occurs during the period from time s to time t;

$$\text{Techch} = \left[\frac{D_i^{\,s}\left(x^t,y^t\right)}{D_i^{\,t}\left(x^t,y^t\right)}\times\frac{D_i^{\,s}\left(x^s,y^s\right)}{D_i^{\,t}\left(x^s,y^s\right)}\right]^{1/2} \tag{4}$$

Represents the technological progress change index that occurrs during the period from time s to time t.

The technical efficiency change index (Effch) is mainly used to measure the distance between the decision unit and the production function, which represents the intensive use efficiency of various input factors. The technology change index (Techch) is mainly used to measure the technical improvement or technological progress. When the technical efficiency change index or technological change index is greater than 1, which means that it is the source of total factor productivity growth, on the contrary, it is the root of all factor productivity reduction. DEA C^2R model can usually be used to solve the Malmquist index, that is, total factor production growth rate.

3. Data Sources and Processing

The sample data of this empirical analysis are derived from the "Jiangxi Statistical Yearbook". It is assumed that two kinds of input factors are needed in the agricultural production process: capital stock and labor force. Output is expressed with expected output GDP and non-expected output of agricultural carbon emissions.

3.1 Capital Stock Input Elements.

Because the agricultural capital stock data of each district can not be obtained directly from the statistical yearbook, this paper adopts the perpetual inventory method to estimate. the formula is as follows:

$$K_t = I_t / P_t + (1-\delta_t)\ K_{t-1} \tag{5}$$

Which is: K_t is agricultural capital stock for each city in the t year, the unit is 100 million yuan; I_t is the fixed assets investment of agriculture, forestry, animal husbandry and fishery in each city, treating 2005 constant price as the base period, using the agricultural fixed capital price index Pt of Jiangxi Province to reduce, but the "Jiangxi Statistical Yearbook" lacks this data. The price index of agricultural production assets refer to the relative number of trends and degrees of price changes of agricultural production data in a certain period, including agricultural hand tools, feed, mechanized farm tools and other agricultural means of production. In the absence of the fixed capital price index of agriculture, this paper argues that it is reasonable to select the price index of agricultural means of production to replace. δ_t is the depreciation rate of capital stock, this paper chose depreciation level $\delta_t = 5\%$ [1] [2]. The fixed capital stock for each city during 2005 base period (K_{2005}), this paper uses the ideas and achievements proposed by Wang Jintian et al. (2007) [3] to calculate and sort out.

3.2 The Elements of Labor Input.

Selecting the number of employees of the city in first industry as the amount of labor input accounting indicators over the years, unit is 10 thousand people.

3.3 Expected Output GDP.

The total output value of agriculture, forestry, animal husbandry and fishery in each district is selected as the basic index to measure the expected output, and it is converted into constant price in 2005, unit is 0.1 billion

3.4 Non-expected Output of Agricultural Carbon Emissions.

Agricultural carbon emissions are diverse and complex, According to the research results of scholars, Jane M.F.Johnson(2007)[4], Tian Yun (2012) [5], there are three main sources of agricultural carbon emission: one is the agricultural land using activity including chemical fertilizers, pesticides, agricultural and sideline agricultural materials directly or indirectly causing carbon emissions, agricultural irrigation activities cause energy consumption, taking the actual using amount as the standard; the second is the greenhouse gas emissions of methane in rice growth and development process, taking the annual rice planting area as the standard, the rice growth cycle take its median value of 130 days; the third is carbon emissions caused by animals, especially ruminants breeding, selecting pigs, cattle, sheep three major livestock as the measure, with reference to the annual data at the end of the year to make appropriate amendments. The formula for building agricultural carbon emissions is as follows:

$$C=\sum C_i=\sum S_i \cdot \omega_i \tag{6}$$

C is the total amount of agricultural carbon emissions in each district, the unit is 10,000 tons; C_i is the carbon emissions of various carbon sources; S_i is the amount of carbon emissions from all resources; ω_i is the carbon emission coefficient of each carbon source. The carbon emission coefficient of each carbon source is shown in Table 1.

Table 1 Carbon emission coefficient of major carbon source

Type	Carbon source	Carbon emission coefficient	Dare reference source
Agricultural land using	chemical fertilizers	0.8956[kg C/kg]	Oak Ridge National Laboratory
	pesticides	4.9341[kg C/kg]	Oak Ridge National Laboratory
	agricultural film	5.18[kg C/kg]	Institute of Agricultural Resources and Ecological Environment, Nanjing Agricultural University
	Agricultural irrigation	20.476[kg C/hm^2]	Dubey(2009)[6] Li Bo(2012)[7]
Rice plant	Rice	3.136g [C/(m^2·day)]	Wang[8], Matthews[9], Cao[10]
Animal breeding	Pig	34.091kg [C/(one·year)]	United Nations Intergovernmental Panel on Climate Change
	cattle	415.91kg [C/(one·year)]	United Nations Intergovernmental Panel on Climate Change
	mutton	35.1819kg [C/(one·year)]	United Nations Intergovernmental Panel on Climate Change

Source: Based on relevant research literature

Since carbon emissions belong to undesirable outputs, it is necessary to measure agricultural total factor productivity under carbon emission constraints, which means when obtain more desirable output, the less unexpected output, the better. So it needs to make negative processing for them, using formula

$$r_{ij} = \frac{\max_i a_{ij} - a_{ij}}{\max_i a_{ij} - \min_i a_{ij}} *99+1 \quad (7)$$

Negative standardization of carbon emissions is converted to a value between [1, 100].

4. Empirical Analysis

4.1 Agricultural Total Factor Productivity Index and its Composition in Jiangxi Province from 2005 to 2014 under the Carbon Emission Constraints.

Using the DEA-Malmquist index method to obtain the total factor productivity index and its composition of agriculture in Jiangxi Province from 2005 to 2014 under the carbon emission constraint (see Table 2)

Table 2 Agricultural total factor productivity index and its composition in Jiangxi Province from 2005 to 2014

Year	Technical efficiency change index effch	Technical progress index techch	Pure technology efficiency change index pech	Scale efficiency change index sech	Total Factor Productivity Change Index tfpch
2005-2006	0.952	1.049	0.964	0.988	0.999
2006-2007	1.072	0.964	1.017	1.054	1.033
2007-2008	0.956	1.035	1.003	0.953	0.989
2008-2009	1.020	1.019	1.010	1.010	1.040
2009-2010	1.057	0.872	1.003	1.054	0.922
2010-2011	1.004	0.956	1.001	1.003	0.960
2011-2012	1.031	0.938	0.987	1.045	0.967
2012-2013	1.025	0.915	1.011	1.014	0.938
2013-2014	1.019	0.927	1.019	1.000	0.945
Average	1.015	0.964	1.002	1.013	0.977

It can be seen from Table 2 that the total factor productivity of agriculture in Jiangxi Province under the constraint of carbon emission is only increasing in 2007 and 2009, which is 3.3% and 4.0% higher than that of the previous year respectively. The value of the total factor productivity TFP in 2005 ~ 2014 is 0.9 to 1.1, showing a wave of decline in the trend. It can be seen that under the carbon emission constraints, the total factor productivity of agriculture in Jiangxi Province does not meet the frontier of production. The development of agriculture still belongs to the traditional extensive growth mode of "high input, high consumption and high output", resources, environment and agricultural economic development are in an uncoordinated state, the total factor productivity can be effectively improved by reducing agricultural resource consumption or carbon emissions.

By dividing the total factor productivity into technical efficiency change index and technological progress index. From the point of view of technological efficiency change, the province's technological efficiency change value is more than 1 in addition to 2006 and 2008, which means that the technology of Jiangxi Province efficiency is progressively improving, with an average of

1.5 percent annual improvement in technical efficiency, with an average of 0.2 percent per year for purely technical efficiency and an average increase of 1.3 percent per year for scale efficiency. From the technical progress index, the province in addition to 2006, 2008, 2009, the other years did not show growth trends, the average annual technological progress index fell 3.6%. This shows that the total factor productivity of agricultural production in Jiangxi Province under the constraint of carbon emission is a typical technological efficiency-driven growth mode, especially through the large-scale investment in agricultural investment, and vigorously develop all kinds of industrial management organizations, especially farmer cooperatives, through the appropriate scale of agricultural management and intensive production to ease the high carbon pressure in the traditional agricultural production and management system; And technological progress for the promotion of carbon emissions under the constraints of Jiangxi Province in the development of agricultural production and management has a great potential space, in order to achieve low-carbon agriculture development, enhance agricultural total factor productivity, relying solely on technological efficiency is far enough, should be by virtue of the development of low-carbon technologies, pay attention to the innovation of low-carbon agricultural technology, introduce and promote new low-carbon agriculture technology, adjust the agricultural investment structure, establishing low-carbon technology-intensive agriculture, such as vigorously promote the slow release of fertilizer, using environmentally friendly plastic sheeting, energy-saving agricultural machinery, developing few land, less water, less energy, leisure agriculture, to taking protecting the resources and environment as the focus, and continuously improve the level of low-carbon technology, accelerate the development of low-carbon agriculture in Jiangxi.

4.2 Total Factor Productivity Index of Agriculture and Composition under the Constraints of Carbon Emissions in 11 Cities of Jiangxi Province from 2005 to 2014.

In the following, applying the DEA-Malmquist index method to analyze the agricultural total factor productivity index and its composition (see Table 3).

Table 3 Agricultural total factor productivity index and its composition in 11 cities of Jiangxi Province from 2005 to 2014

Region	Technical efficiency change index effch	Technical progress index techch	Pure technology efficiency change index pech	Scale efficiency change index sech	Total Factor Productivity Change Index tfpch
Nanchang	1.000	0.937	1.000	1.000	0.937
Jingdezhen	1.019	0.950	1.000	1.019	0.968
Pingxiang	1.016	0.968	1.000	1.016	0.983
Jiujiang	1.074	1.003	1.000	1.074	1.077
Xinyu	1.000	0.990	1.000	1.000	0.990
Yingtan	0.997	0.892	1.000	0.997	0.889
Ganzhou	1.046	0.841	1.000	1.046	0.880
Jian	1.000	1.015	1.000	1.000	1.015
Yichun	1.000	0.880	1.000	1.000	0.880
Fuzhou	0.989	1.073	0.999	0.990	1.061
Shaorao	1.020	1.050	1.019	1.001	1.071
Average value	1.015	0.964	1.002	1.013	0.977

It can be seen from Table 3 that from the technical efficiency indicators, Jiangxi Province in addition to Yingtan City, Fuzhou City, efficiency indicators of the other cities are greater than 1, that is, from 2005 to 2014, most of the cities of Jiangxi Province have made great progress in resource allocation, and by accelerating the innovation of agricultural management system, it has done great efforts to support and cultivate the main types of new agricultural production and management, such as large-scale professional households, family farms and farmer cooperatives, to improve the degree of agricultural organization and promote the scale of agricultural land management, thereby enhancing the efficiency of Jiangxi low-carbon agricultural production. From the technical progress indicators, the level of low-carbon agricultural technology of Jiujiang City, Ji'an City, Fuzhou City, Shangrao City continue to increase, indicating that the four cities attach importance to scientific and technological progress on the role of agricultural economic growth, through continuous improvement of agricultural technology innovation system, to increase the agricultural low-carbon technology to promote investment, and speed up the farmers to improve the quality of science and technology and technology management, improve farmers' willingness to accept low-carbon technology and the ability and other effective measures, through introducing low-carbon agricultural technology to achieve total agricultural productivity growth.

The total factor productivity of agriculture in 11 cities of Jiangxi Province under the constraint of carbon emission have a certain difference. From 2005 to 2014, the majority of cities and municipalities show the phenomenon that the efficiency of agricultural technology are improved and the technological progress is slow. The decline of technological progress index is more than the improvement of technological efficiency, consistent with the overall level of Jiangxi Province, indicating that these districts attached more attention to improving the management efficiency and scale efficiency of agriculture, relatively ignoring the investment in agricultural science and technology innovation, the introduction of new agricultural low-carbon technologies and promotion is not good enough. It is pointed out that the increase of total factor productivity of agriculture under the constraint of carbon emission depends on the improvement of technical efficiency. To promote the total factor productivity of agriculture in Jiangxi Province, we should pay attention to the improvement of low-carbon technology and put sustainable development in the first place.

5. Conclusion

First, because technological progress has become the core driving force for the growth of agricultural total factor productivity in Jiangxi Province under the carbon emission constraints, in order to promote the improvement of total factor productivity of agriculture, it is necessary to innovate the low-carbon technology of agriculture and vigorously promote all kinds of new low-carbon agriculture technologies, the transformation of the application of results, and effectively improve the efficiency of agricultural production data, reduce energy consumption per unit of agricultural output, promote resource-saving and environment-friendly recycling agriculture, to achieve carbon reduction of agricultural.

Second, from the regional point of view, under the constraints of carbon emission in 11 urban areas of Jiangxi Province in agricultural total factor productivity have some differences, some cities and counties in the uncoordinated state of agricultural production with resources and the environment. Different regions should be based on the characteristics of regional differences, combining with their own resource endowments, implementing differentiated countermeasures for resources and environmental management. The government should formulate a reasonable public policy to speed up the introduction, innovation and diffusion of advanced low-carbon technologies, and increase investment in the construction of agricultural environmental management infrastructure, thus narrowing the gap between the urban areas in the low-carbon technologies.

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