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Analysis on the Growth and Convergence of Agricultural Green Total Factor Productivity in Guangxi

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Abstract

This paper uses DEA-SBM super-efficiency model and GML index to calculate the agricultural green total factor productivity (AGTFP) of Guangxi from 2014 to 2020, and analyzes the convergence of AGTFP and its influencing factors. The study finds that: First, Guangxi's AGTFP increased by 5.42% annually, mainly driven by the agricultural green technology progress; Second, the growth of AGTFP in different regions exists heterogeneous, and the growth rate of western Guangxi ranks first in Guangxi; Third, the AGTFP in Guangxi shows a state of first σ converges and then σ diverges, there is absolute β convergence in AGTFP in Guangxi, this phenomenon exist in northern Guangxi, central Guangxi, southern Guangxi and eastern Guangxi, but there is no absolute β Convergence in western Guangxi ; Fourth, agricultural structure inhibits AGTFP, while the level of fiscal support for agriculture promotes AGTFP.

Keywords

Guangxi; Agricultural Green Total Factor Productivity; DEA-SBM Super Efficiency Model; GML Index.

1. Introduction

Since the reform and opening up from 1978, China's land system reform has greatly mobilized the enthusiasm of farmers in production and achieved the rapid growth of China's total agricultural output value. However, China's agricultural development still faces the challenge of high chemical input and agricultural non-point source pollution emissions. How to solve the agricultural development dilemma to achieve agricultural green development has become the key to deepening the agricultural supply-side structural reform[1]. Guangxi is an important area of agricultural production in China, but its long-standing extensive agricultural production mode is excessively dependent on the input of factors, which leads to the increase of agricultural output and the slow development of its agricultural economy [2]. Therefore, in the "Fourteenth Five-Year Plan", the Guangxi government proposed to improve the green and low-carbon development system, adopt environment-friendly and resource-saving agricultural production methods to reduce agricultural non-point source pollution. Traditional agricultural productivity ignores the environmental damage caused by unexpected output in the process of agricultural production, and it is difficult to accurately reflect the green development of agriculture in Guangxi, while the AGTFP with comprehensive consideration of environmental pollution factors can better reflect the dual economic and environmental benefits of current agricultural development in Guangxi [3]. So, what is the growth of AGTFP in Guangxi? How is the convergence of AGTFP in Guangxi? These are urgent problems to be solved.

Agricultural productivity growth is one of the fundamental issues in China's agricultural development [4]. Traditional total factor productivity only considers capital and factor inputs, but ignore resources and environmental factors, which makes the estimated agricultural development situation deviate. In view of this defect, some scholars put resources and environmental pollution factors into the model when calculating agricultural productivity, and call it AGTFP [5-7]. After investigating the existing research, it is found that different scholars choose different measurement methods and indicators, and the final research conclusions on AGTFP are also significantly different. In terms of calculation methods, the academia mostly adopts the stochastic production frontier analysis (SFA) and data envelopment analysis (DEA). Among them, DEA can overcome the efficiency deviation caused by multi-input and multi-output, and is widely used in productivity evaluation [8-9]. However, because the traditional Malmquist index cannot measure the green total factor productivity with comprehensive consideration of unexpected output such as environmental pollution, some scholars use the ML productivity index to solve the problem of measurement deviation without considering unexpected output [10-12]. At the same time, the non-radial and non-angular super-efficiency SBM directional distance function can effectively solve the error problem of ordinary DEA methods [13].

In the selection of measurement indicators, some scholars regard agricultural non-point source pollution (such as chemical drug residues from agricultural activities) as an unexpected output [14-16]. The other part of the study is to take the carbon dioxide emissions in agricultural activities as an unexpected output [17-18]. However, in real agricultural production, the use of pesticides and agricultural film will produce soil pollution residues, the use of chemical fertilizers will cause water pollution, and the use of diesel oil and tillage activities will also cause carbon emissions [19]. Only considering agricultural non-point source pollution or agricultural carbon emissions will lead to the deviation of the calculation results [20]. According to the existing literature, the current research on agricultural productivity in Guangxi has not included the resources and environment factors. The only two studies only measure the agricultural production efficiency and agricultural total factor productivity in Guangxi [21-22], which cannot accurately reflect the current situation of agricultural green development in Guangxi.

To sum up, there is still a research gap in the existing research on agricultural green total factor productivity of in Guangxi. This paper will expand existing literatures from the following three aspects: firstly, the AGTFP of Guangxi will be calculated by comprehensively considering various types of environmental pollution output such as soil residue, water pollution, gas emissions, etc. in agricultural production in Guangxi; Secondly, this paper will use the non-radial and non-angle SBM super-efficiency model and GML index method to calculate the AGTFP in Guangxi. This method can effectively overcome the measurement bias caused by the choice of input or output angle, and can solve the problem that the effective decision-making units cannot be sorted; Finally, this paper applies σ Convergence and β Convergence method to analyze the convergence and influencing factors of AGTFP in Guangxi.

2. Model Setting, Data Selection and Indicator Processing

2.1. Calculation Method

This paper uses the SBM super-efficiency model and GML index method to calculate the AGTFP in Guangxi. Suppose there are k decision units (j=1,2,..., n), and each decision unit includes the input vector x ∈ RM (i=1,2,..., m), the expected output yg ∈ Rs1, and the expected output yb ∈ Rs2. At the same time, define the matrix: $X = [x_1, x_2, \dots x_n] \in R^{m\times n}$, $Y^g = [y_1^g, \dots, y_n^g] \in R^{s_1\times n}$, $Y^b = [y_1^b, \dots, y_n^b] \in R^{s_2\times n}$. Then the SBM super-efficiency model of the decision units k can be expressed as follows:

$$\min\rho = \frac{1+\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{ik}}}{1-\frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1} s_r^g/y_{rk}^g+\sum_{t=1}^{s_2} s_t^b/y_{tk}^b\right)} \tag{1}$$

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$$s.t. \quad x_{ik} \geq \sum_{j=1,j\neq k}^{n} x_{ij}\lambda_j - s_i^-$$

$$y_{rk}^g \leq \sum_{j=1,j\neq k}^{n} y_{rj}\lambda_j + s_r^+$$

$$y_{tk}^b \geq \sum_{j=1,j\neq k}^{n} y_{tj}\lambda_j - s_t^b$$

$$\lambda \geq 0,\ s^g \geq 0, s^b \geq 0, s^- \geq 0$$

In Formula (1), s represents the relaxation variable, λ represents the weight vector, and ρ represents the efficiency value of decision units k, its value can be greater than 1, so effective decision units can be sorted. Considering that the SBM super-efficiency model calculates the static productivity, which can only reflect the green development of agriculture in Guangxi in a certain year. Therefore, this paper refers to the research method of Oh (2010) [23]and uses GML index to calculate the AGTFP in Guangxi. The GML index is expressed as follows:

$$\mathrm{GML}^{t,t+1}(x^{t+1},y^{t+1},b^{t+1};x^t,y^t,b^t) = \frac{1+D^G(x^t,y^t,b^t)}{1+D^G(x^{t+1},y^{t+1},b^{t+1})} \tag{2}$$

If the non-expected output decreases and the expected output increases, then $\mathrm{GML}^{t,t+1} > 1$ indicates that the AGTFP is higher than the level of the previous period, and the agricultural green development is improved, and vice versa. GML index can be further decomposed into agricultural green technology progress (GTC) and agricultural green technology efficiency (GEC):

$$\begin{aligned} &\mathrm{GML}^{t,t+1}(x^{t+1},y^{t+1},b^{t+1};x^t,y^t,b^t) \\ &= \frac{1+D^t(x^t,y^t,b^t)}{1+D^t(x^{t+1},y^{t+1},b^{t+1})} \times \left[\frac{\frac{1+D^G(x^t,y^t,b^t)}{1+D^t(x^t,y^t,b^t)}}{\frac{1+D^G(x^{t+1},y^{t+1},b^{t+1})}{1+D^{t+1}(x^{t+1},y^{t+1},b^{t+1})}}\right] \\ &= \frac{TE^{t+1}}{TE^t} \times \left[\frac{BPG_{t+1}^{t,t+1}}{BPG_t^{t,t+1}}\right] = \mathrm{GEC}^{t,t+1} \times \mathrm{GTC}^{t,t+1} \end{aligned} \tag{3}$$

In Formula(3), $\mathrm{GEC}^{t,t+1}$ and $\mathrm{GTC}^{t,t+1}$ are real numbers greater than 0. When their numerical values are greater than 1, they respectively represent the improvement of agricultural green technology efficiency and the progress of agricultural green technology. When their numerical values are less than 1, it means that the efficiency of agricultural green technology is reduced and agricultural green technology is retrogressed.

2.2. Data Selection

The time span of the data in this paper is 2014-2020. A total of 14 prefecture-level cities in Guangxi are selected as the research objects to calculate the AGTFP. Input variables include land input, irrigation input, mechanical labor input, labor input, pesticide input, agricultural film input and fertilizer input. The output includes expected output and non-expected output. The expected output is the total agricultural output value of Guangxi in constant prices; Unexpected output includes different kinds of pollutants produced in agricultural production activities, including phosphorus and nitrogen loss and chemical oxygen demand in agricultural water pollution, carbon emissions from agricultural production activities, and pesticide and agricultural film residues in agricultural soil. The above data are publicly obtained according to the application. The specific definitions and descriptions of each variable are shown in Table 1.

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Table 1. Definition and description of each variable

<table>
<tr><th></th><th>Variable name</th><th>Variable description</th></tr>
<tr><td rowspan="7">Input variables</td><td>Land input</td><td>The total planting area of crops</td></tr>
<tr><td>Irrigation input</td><td>The actual effective irrigation area of each city</td></tr>
<tr><td>Mechanical labor input</td><td>The total power of agricultural machinery</td></tr>
<tr><td>Labor input</td><td>The total labor force of planting industry</td></tr>
<tr><td>Pesticide input</td><td>Pesticide usage</td></tr>
<tr><td>Agricultural film input</td><td>Amount of agricultural film used</td></tr>
<tr><td>Fertilizer input</td><td>The amount converted from fertilizer application</td></tr>
<tr><td rowspan="3">Output variables</td><td>Expected output</td><td>Total agricultural output value of all cities in Guangxi</td></tr>
<tr><td rowspan="2">Unexpected output</td><td>The agricultural comprehensive pollution index</td></tr>
<tr><td>Agricultural carbon emissions</td></tr>
</table>

3. Analysis of the Calculation Results of AGTFP in Guangxi

3.1. Growth and Decomposition of AGTFP in Guangxi

This paper uses SBM super-efficiency model and GML index to calculate the AGTFP of 14 prefecture-level cities in Guangxi. In general, from 2014 to 2020, the average annual growth rate of AGTFP in Guangxi was 5.42%, mainly driven by agricultural green technology progress (6.78%). Among them, the growth rate of AGTFP in Guangxi was relatively high in 2015-2016. During this period, the Guangxi government issued a series of policies to help rural economic development, such as investing in comprehensive agricultural development funds, increasing the investment in the grain production plan, and implementing comprehensive transformation measures against agricultural land pollution. In addition, the Guangxi government also vigorously promoted rural revitalization in 2018, expanded financial subsidies to farmers, and helped agricultural environmental protection and non-point source pollution prevention and control, which made the growth rate of agricultural green technology progress in Guangxi reach 27.08% in 2018-2019, and promoted the growth of AGTFP (20.18%).

Table 2. Changes and decomposition of AGTFP in Guangxi from 2014 to 2020

Year	AGTFP	GEC	GTC	Region	AGTFP	GEC	GTC
2014-2015	0.9778	1.0148	0.9668	Northern	1.0302	1.0000	1.0290
2015-2016	1.1199	0.9767	1.1528	Central	1.0300	0.9743	1.0597
2016-2017	1.0314	0.9662	1.0689	Eastern	1.0554	0.9906	1.0657
2017-2018	0.9945	1.0538	0.9584	Southern	1.0612	1.0042	1.0608
2018-2019	1.2018	0.9641	1.2708	Western	1.0706	1.0188	1.1171
2019-2020	1.0001	1.0114	0.9890	Total	1.0542	0.9978	1.0678

Note: The average value in the table is the arithmetic average value.

3.2. Regional Differences in the Growth of AGTFP in Guangxi

From the perspective of AGTFP in different regions of Guangxi, the average annual growth rate of AGTFP in northern, central, eastern, southern and western Guangxi during 2014-2020 was

3.02%, 3.00%, 5.54%, 6.12% and 7.06% respectively. The reason for the rapid growth of AGTFP in western Guangxi may be that compared with other regions in Guangxi, the agricultural green development in western Guangxi is in a relatively backward state. After improving agricultural infrastructure and introducing agricultural machinery, its agricultural green technology progress has achieved rapid growth. It can be seen from Table 2 that the progress rate of agricultural green technology in western Guangxi is 11.71%, which is higher than that in other regions, while the average annual decline of agricultural technology efficiency in central and eastern Guangxi is 2.57% and 0.94%, which may be due to the frequent geological disasters in these two regions offset the positive impact of agricultural green technology progress.

3.3. Growth of AGTFP in All Cities

During the whole research period, the growth rate of AGTFP in six cities exceeded the average annual growth rate of 5.42% in Guangxi, among which the average annual growth rate of AGTFP in Nanning, Baise and Fangchenggang was 16.95%, 11.64% and 8.15%, ranking the top three. From the perspective of agricultural green technology efficiency, the numerical value of 9 cities is less than 1, where are Liuzhou, Laibin, Guigang, Yulin, Hezhou, Beihai, Qinzhou, Chongzuo and Hechi, indicating that the catch-up speed of agricultural green technology efficiency in these 9 cities is slower than that of agricultural green technology progress in areas with rapid agricultural production [23]. From the perspective of agricultural green technology progress, the agricultural green technology progress rate of Liuzhou, Wuzhou, Nanning, Qinzhou and Baise exceeded the average of Guangxi (6.78%). In addition, the AGTFP of Laibin and Chongzuo showed a downward trend. The reason may be that although the agricultural green technology progress of Laibin and Chongzuo showed a growth trend, the decline of their agricultural green technology efficiency offset the positive impact of agricultural green technology progress, resulting in the decline of their AGTFP.

4. Convergence and Influence Factor Analysis of AGTFP in Guangxi

4.1. Analysis of σ Convergence of AGTFP

From the above analysis, it can be seen that there are certain regional growth differences in AGTFP among different regions in Guangxi, but the above results cannot reflect the temporal variation gap of AGTFP among different regions. Therefore, this paper further uses convergence analysis method to explore, and constructs σ convergence as follows:

$$\sigma_t = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left\{E_i(t) - \left[\frac{1}{n}\sum_{j=1}^{n} E_j(t)\right]\right\}^2} \tag{4}$$

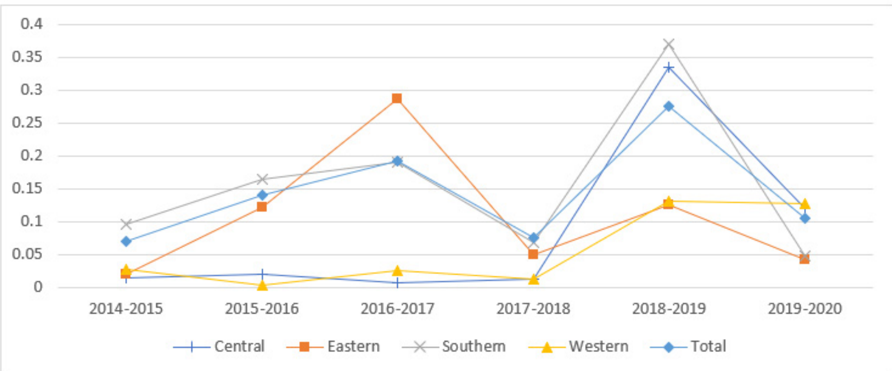

Figure 1. Analysis of σ convergence in various regions of Guangxi during 2014-2020

Note: Since only Guilin is included in northern Guangxi, the convergence of σ cannot be measured, so Figure 1 does not include northern Guangxi.

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In Formula (4), represents the AGTFP of the I-th region in year t, and n is the number of individuals in the region. If the σ value of t+1 period is less than that of t period, it indicates that the AGTFP in the measurement period is in a convergence state, and the gap between different individuals in the study area is decreasing.As can be seen from Figure 1, the convergence of σ in AGTFP in Guangxi shows an M-shaped change trend, and the overall trend in eastern and southern Guangxi is roughly the same as that in Guangxi. After 2017-2018, the AGTFP of Guangxi and the eastern and southern Guangxi regions showed significant fluctuations, while the central and western Guangxi regions began to show dramatic fluctuations in 2018-2019.

4.2. Absolute β Convergence Analysis of AGTFP in Guangxi

If the initial value of AGTFP is relatively low, but its growth rate is faster than the initial value of AGTFP is relatively high in the study region, it indicates that there is absolute β convergence in this region. In this paper, the absolute β convergence model is constructed as follows:

$$LnAGTFP_{i,t+1} - LnAGTFP_{i,t} = \alpha + \beta LnAGTFP_{i,t} + \varepsilon_{i,t} \tag{5}$$

Where, is the AGTFP measured in region i during period t, is a random interference term, and the value of coefficient β is less than 0, indicating that there is absolute β convergence in the study region. Table 3 shows the estimation results of OLS model, indicating that the AGTFP of Guangxi has absolute β convergence, indicating that the regions with low initial value of AGTFP have relatively high growth rate, that is, there is a certain degree of "catch-up effect". The absolute β convergence also exists in North, South, middle and east Guangxi, but not in West Guangxi, indicating that the growth of AGTFP in west Guangxi is gradually expanding.

Table 3. Results of absolute β convergence in different regions of Guangxi during 2014-2020

	Total	Northern	Southern	Central	Western	Eastern
α	1.739**	1.832**	1.722***	1.472*	-1.033	2.027**
Standard error	0.425	0.556	0.261	0.545	0.578	0.413
β	-1.648**	-1.747**	-1.615***	-1.398*	1.082	-1.953**
Standard error	0.402	0.520	0.246	0.518	0.615	0.434
Adjust-R^2	0.798	0.720	0.913	0.611	0.334	0.843

Note: "***, **, *" represent significance levels of 1%, 5%, and 10%, respectively.

4.3. Influencing Factors of AGTFP

At the same time, in order to identify different factors affecting the growth of AGTFP in Guangxi, this paper further constructed the panel data regression model as follows:

$$AGTFP_{i,t} = \alpha + \beta_1 INS_{it} + \beta_2 IND_{it} + \beta_3 TRA_{it} + \beta_4 FSA_{it} + \varepsilon_{i,t} \tag{6}$$

Where INS_{it}, IND_{it}, TRA_{it}, FSA_{it} is the influencing factor of AGTFP in Guangxi, and is the random disturbance term. The variables are described as follows: (1) Agricultural structure (INS), expressed by the proportion of the added value of planting industry in the added value of agriculture, forestry, animal husbandry and fishery. (2) Income distribution (IND), expressed as the ratio of urban per capita disposable income to rural per capita net income. (3) Trade dependency (TRA) is expressed as the ratio of the total value of regional agricultural imports and exports to agricultural added value. (4) The level of financial support to agriculture (FSA) is expressed as the proportion of agricultural, forestry and water affairs expenditure to total financial expenditure. The above data are mainly from Guangxi Statistical Yearbook. For the data related to monetary measurement, this paper has carried out comparable price processing.

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Table 4. Influencing factors of AGTFP in Guangxi

Variable	Coefficient	Standard error
INS	-0.961*	0.499
IND	0.033	0.101
TRA	-0.005	0.004
FSA	0.027*	0.016
Within-R^2	0.113	
F statistics	2.37*	

Note: "***, **, *" represent significance levels of 1%, 5%, and 10%, respectively.

The bidirectional fixed effect model was used for regression, and the estimated results were shown in Table 4. Among them, agricultural structure has a negative impact on AGTFP in Guangxi. According to the bulletin of the second national pollution source survey in Guangxi, currently, pollution emissions from planting industry have become the main component of agricultural non-point source pollution. Therefore, the increasing proportion of planting industry in agriculture, forestry, animal husbandry and fishery will inevitably have a negative effect on the growth of AGTFP. In addition, fiscal support for agriculture policy has a significant positive impact on AGTFP. It can be seen that the more the government spends on agriculture, the more favorable it is for farmers to buy green production factors, thus reducing agricultural non-point source pollution. At the same time, the strengthening of fiscal support for agriculture also indicates that the government attaches more importance to the green development of agriculture, which can also reduce the cost constraints of agricultural production, improve agricultural profits, and thus improve the green total factor productivity of agriculture.

5. Conclusion and Policy Recommendations

In this paper, 14 prefecture-level cities in Guangxi Region during 2014-2020 are taken as the research object, and various environmental pollution emissions such as soil residual pollution, water pollution and gas emissions are taken as the non-expected outputs. DEA-SBM super efficiency model is used to calculate the AGTFP of each prefecture-level city in Guangxi, and its convergence and influencing factors are analyzed. The results show that: (1) The annual growth rate of AGTFP in Guangxi is 5.42%, which is mainly driven by the progress of agricultural green technology (6.78%). (2) AGTFP in Guangxi has great volatility. From the perspective of time, the growth rate of AGTFP was higher in 2015-2017 and 2018-2019, but decreased by 2.22% and 0.55% in 2014-2015 and 2017-2018, respectively. From a regional perspective, the annual growth rate of AGTFP in western Guangxi was the highest (7.06%), while that in central Guangxi was the lowest (3.00%). There was a significant difference between different regions in AGTFP. (3) The convergence value of σ of AGTFP fluctuates greatly in all regions of Guangxi; The absolute β convergence of AGTFP in Guangxi indicates that the regions with low AGTFP have relatively high growth rate. The absolute β convergence exists in northern, central and southern Guangxi, but not in western Guangxi. (4) Agricultural structure negatively affected AGTFP in Guangxi, while fiscal support for agriculture positively promoted AGTFP.

Based on the above conclusions, we put forward the following policy suggestions: (1) The research shows that the AGTFP of Guangxi is mainly driven by the progress of agricultural green technology, while the contribution of agricultural green technology efficiency is small. Therefore, on the premise of ensuring the progress speed of agricultural green technology, attention should be paid to improving the efficiency of agricultural green technology. Through improving the utilization rate of agricultural machinery, the utilization rate of agricultural input factors, increasing the investment in agricultural green technology and other measures, the

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optimal allocation of resources should be realized, so as to improve the efficiency of agricultural green technology. (2) Considering that the growth of AGTFP in different regions of Guangxi is not balanced, and the growth of AGTFP in western Guangxi has a gradually expanding trend. Therefore, regions with slow growth of AGTFP should be encouraged to learn from regions with fast growth, so as to achieve balanced development of AGTFP in all regions of Guangxi in the mode of "the first rich drives the latter rich". (3) From the perspective of the main influencing factors of AGTFP in Guangxi, the imbalance of agricultural structure will also have an important impact on AGTFP. While developing planting industry and increasing the total amount of agricultural products, it is necessary to strictly control the input of pesticides, fertilizers and agricultural pollution emission; At the same time, financial support to agriculture should be further strengthened to reduce the cost constraints of agricultural producers, so as to promote the growth of AGTFP.

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