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Measurement and evolution characteristics of agricultural green total factor productivity in Fujian Province

Feng Xie[1], Qiao Quan[2], Qingqing Yuan[3], Ketao Lin[4] and Jie Ye[5]

[1,2,3]Fujian Agriculture and Forestry University, Fuzhou, China

[4,5]Quanzhou Normal University, Quanzhou, China

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ABSTRACT

For a long time, the traditional crude mode of agricultural production makes the agricultural surface pollution deepening, the agricultural development mode for the green transformation of the demand is very urgent, accelerate the green transformation of the agricultural development mode, enhance the agriculture green TFP of is to promote the sustainable development of agriculture is an effective path. Therefore, using panel data from 9 municipal-level administrative districts in Fujian Province from 2011 to 2021 and Accounting for Agricultural Green TFP in Fujian Province Using the MML Index Method. Conclusion: (1) Fujian Province's agricultural green TFP has grown at an average annual rate of 2.35%, and its growth has been mainly due to technological advances since agriculture and improved technical efficiency; (2) Differences in agricultural green TFP growth rates and growth drivers across subregions; (3) Most cities have achieved positive growth in agricultural green TFP, and agricultural technological progress and innovation have played a greater role in boosting agricultural green TFP. Based on the conclusions of the study, it is proposed to promote the growth of agriculture green TFP in from the perspectives of promoting the output of green technology in agriculture, constructing a balanced pattern of agricultural development in various regions, and combining their functional advantages in accordance with local conditions.

Keywords: Fujian Province; Agricultural green TFP; Sustainable development; Technological advances in agriculture

1. Introduction

The twentieth report has made important deployments for green development, including the green transformation of development methods, pollution prevention and the promotion of carbon

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peaking and carbon neutrality. For a long time, the agricultural growth potential driven by traditional production inputs has gradually weakened, and energy and environmental problems have become increasingly prominent, making the external conditions for sustainable agricultural development continue to deteriorate, and relying on the green transformation of the agricultural development mode to enhance the green total factor productivity in agriculture has become an effective path to crack the reality of the predicament of agriculture (Guo & Liu, 2021). Agricultural total factor productivity (TFP), as one of the important indicators characterizing the level of agricultural production (Gan et al., 2022), is the key to promoting the healthy and high-quality development of agriculture (Liu, 2021). In the past, China's agriculture has realized a certain growth of agricultural total factor productivity through crude agricultural production at the cost of consuming a large number of agricultural production factors and sacrificing the agricultural ecological environment, but this is obviously not in line with the requirements of the green transformation of China's agricultural development mode. Therefore, realizing the green and sustainable growth of agricultural total factor productivity is an inevitable choice to break the dilemma faced by the current agricultural development and promote the growth rate and quality of agricultural development. Fujian Province as China's eastern coastal economic province and the first national ecological civilization pilot area, the level of agricultural economic development is not completely constrained by the geographic pattern of "eight mountains, one water, one field", and in recent years, it is relying on the characteristics of the modern agricultural model to promote the level of agricultural development continued to improve, but this way of improvement is based on the rough production, there are unsustainable, development and environmental protection. However, this way of upgrading is mainly based on the rough production, which has the problems of unsustainable, difficult to balance the development and environment, and low quality of development. Therefore, taking Fujian Province as the research object, accounting for green total factor productivity in agriculture and analyzing its evolution characteristics can provide empirical references for the transformation of green agricultural development in Fujian Province or other provinces with regional characteristics.

2. Literature review

Agricultural green total factor productivity can not only measure the utilization efficiency of various agricultural production factors, but also comprehensively consider the impact of non-desired outputs in agricultural production, so it can significantly reflect the efficiency of agricultural green development in the study area (Liu et al., 2021). Currently, the mainstream agricultural TFP measurement can be divided into non-production frontier surface method and production frontier surface method (Lin & Mao, 2023), and the non-production frontier surface method often uses the Solow residual method (He, 2024) and the Tornqvist-Theil index (Fan &

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Zhang, 2002), however, these two types of methods are likely to neglect the technological inefficiency, which may lead to the final results of the final measurements and the actual results of the deviation. With the gradual visualization of the quantities of various factor inputs and outputs in the agricultural production chain, the measurement of agricultural TFP has been gradually improved, and the production frontier surface method has begun to be applied. Initially, scholars used stochastic frontier analysis (SFA) to measure agricultural TFP (Liu & Zhang, 2017) (Liu et al., 2015) (Quan, 2009), and as scholars' understanding of TFP has deepened, data envelopment analysis (DEA) has been more widely used than SFA (Fan & Li, 2012). DEA can treat multiple input and output variables compared to SFA, with the DEA-Malmquist index measuring agricultural TFP being the most commonly utilized (Yin et al., 2014) (Du, 2015). Due to the crude agricultural production methods, agricultural surface source pollution has been deepening, scholars began to pay attention to the impact of the agricultural production process, such as waste exhaust, etc., on the TFP measurement, the use of the ML index to incorporate the impact of non-desired outputs on the measurement of agricultural green TFP (Liu, 2015) (Min & Li, 2012), in addition to other methods, including the SBM-GML index, the SBM-ML index and other methods can measure the agricultural Green TFP.

From the above, it can be seen that scholars mainly focus on the large regional and provincial levels when measuring agricultural TFP, which provides many worthy references for this paper. However, as far as studies at the provincial level are concerned, there are fewer studies that simultaneously take into account the effects of differences in agricultural production frontiers and non-desired outputs on agricultural TFP in the provinces, while the application of the MML productivity index can effectively take into account the effects of differences in production frontiers and non-desired outputs at the same time. Therefore, based on the panel data of nine prefecture-level cities in Fujian Province from 2011 to 2021, this paper applies the MML productivity index to measure the green TFP of agriculture by considering the environmental factors and the impacts of different production frontiers (Oh, 2010), which is able to more accurately obtain the results of the green TFP of agriculture in the province, with a view to providing certain references for the objective evaluation of the development of agriculture in the province.

3. Research methodology and data sources

3.1 Model selection

In the process of agricultural production, the input of the corresponding factors of production, you can get the desired output and non-desired output, the desired output generally refers to the gross agricultural product or food production, etc., and the non-desired output generally refers to the production of agricultural production accompanied by the production of exhaust gas, wastewater, and surface pollution, etc., which is not conducive to the subsequent production of agricultural production and the sustainable development of green agriculture. Clarifying the specifics of agricultural production, this study used the MML productivity index to measure green TFP in agriculture. Assume that T represents each period and t = 1, 2, 3..., and K represents the decision making unit (DMU) and K = 1, 2, 3.... The factors of production invested in each DMU in agricultural production are of type M (x = (x1, ... xM-1, xM) ∈ RM+), which ultimately leads to desired outputs of type N (y = (y1, ... yN-1, yN) ∈ RN+) and undesired outputs of type P (b = (b1, ... bP- 1, bP) ∈ RP+). Suppose again that the production possibility set (PPS) P(x) is the feasible output set for a given input vector x, satisfying the closed set and convexity conditions. Then the model of this (PPS)P(x) can be constructed as in Eq. (1),Since Eq. (1) satisfies the closed set and is bounded, it also needs to satisfy the three axioms of Eq. (a)(b)(c).

$$P(x) = \{(y,b) | x \in (y,b), \ x \in \mathrm{R}_{+}^{\mathrm{M}}\} \qquad (1)$$

$$(y,b) \in P(x), \ y' \leq y \qquad (y',b) \in P(x) \qquad (a)$$

$$(y,b) \in P(x), \ b = 0 \qquad y = 0 \qquad (b)$$

$$(y,b) \in P(x), \ 0 \leq \theta \leq 1 \qquad (\theta y, \theta b) \in P(x) \qquad (c)$$

The axiom of equation (a) shows the case where desired output y is variable when non-desired output is certain. The axiom in equation (b) shows that the production decision-making unit (DMU) cannot produce a desired output in the absence of a non-desired output, i.e., without a non-desired output, there is no desired output. The axiom in equation (c) implies that non-desired output is weakly reducible, and that if desired output decreases under the assumed inputs of agricultural factors of production, non-desired output will also decrease proportionately (Chen & Qin, 2014), which suggests that a reduction in non-desired output comes at the cost of reducing the efficiency of agricultural production. Controlling the generation of pollutants means that any abatement activities in production usually divert resources away from the production of desired outputs, thus affecting the efficiency of agricultural production. Although (PPS)P(x) is well defined from a conceptual point of view, there are some difficulties if applied in empirical analysis, for this reason, the following section applies the Directional Distance Function (DDF) to establish a theoretical equivalent structure for output correction.

3.1.1 Directional distance function

To realize the green and sustainable development of agriculture, it is necessary to make the agricultural production process to maintain a positive growth of desired outputs while ensuring a

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continuous reduction of non-desired outputs, so that the agricultural production method is green and sustainable. The Shephard output distance function is generally used to account for the process of increasing desired output and decreasing non-desired output, non-proportionalized in a given direction. The Directional Distance Function (DDF) is set to maximize the output of desired outputs in the production process while minimizing the output of undesired outputs. The directional distance function (DDF) is set as shown below:

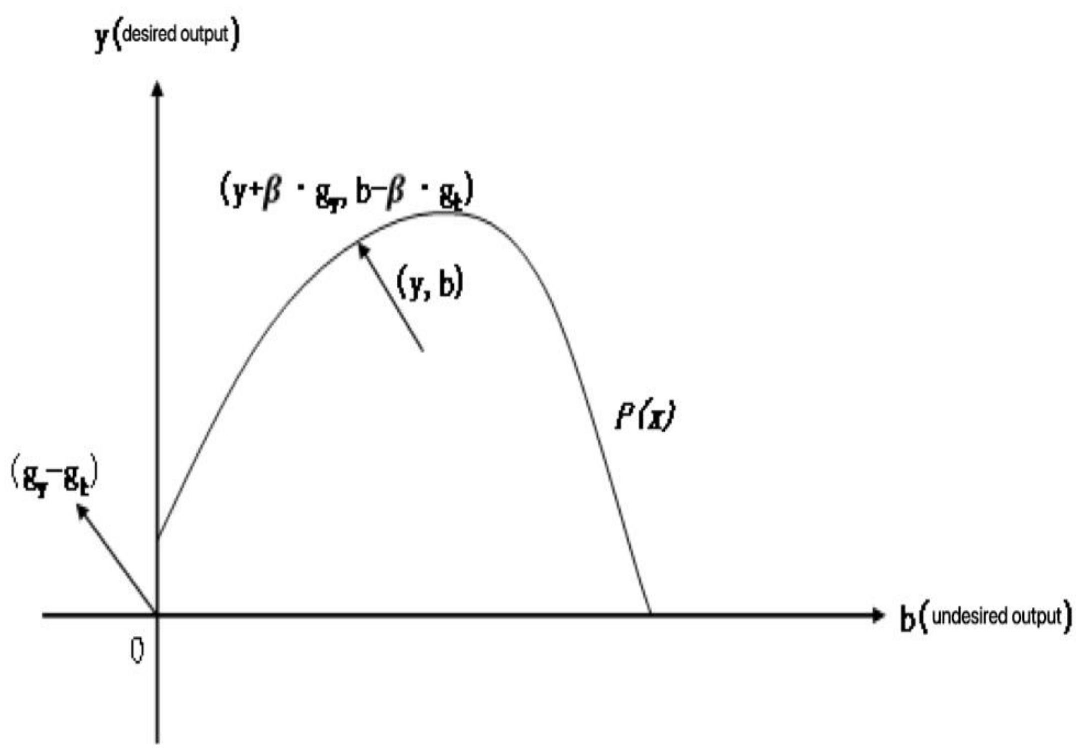
$$\vec{D}(x, y, b; \vec{g}) = max\{\beta: (y + \beta\vec{g}_y, b - \beta\vec{g}_b) \in P(x)\} \qquad (2)$$

(2) where $\vec{g}$ is the direction vector. $\vec{g}$=($\vec{g}_y$, $\vec{g}_b$) . Subsequently, it was found that $\vec{g}$ is observable (Chuang et al., 1997) with direction vectors as observables and $\vec{g}$ = (y,b). Therefore, equation (2) is rewritten as equation (3) as follows.

$$\vec{D}(x, y, b; \vec{g}) = max\{\beta: ((1 + \beta)y, (1 - \beta)b) \in P(x)\} \qquad (3)$$

(3) is the simulated production process that seeks to increase desired output y by β% while non-desired b decreases by β%. This is shown in Figure 1.

Fig. 1 Directional distance function



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3.1.2 MML productivity index

Agriculture is an industry that is sensitive to natural conditions, and under normal circumstances there are large differences in agricultural production methods and production techniques used between different regions, leading to large differences in the efficiency of agricultural production in different regions. Although the differences in the production technology frontier at the provincial level are smaller relative to the differences between provinces, and most of the previous studies have ignored the differences in the agricultural production technology frontier at the provincial level, it has been pointed out in the literature that most of the studies on the measurement of agricultural TFP do not take into account the impact of the heterogeneity of the agricultural production technology frontier in each region of the province, which often leads to biased measurement results (Du et al., 2022). Therefore, this study argues that the heterogeneity of the technological frontiers that exist in each city of Fujian Province needs to be taken into account when measuring the green total factor productivity of agriculture in each city. Defining and Decomposing the MML Productivity Index Applying the Global Benchmarking Technique (GBT) proposed by Tulkens and Vanden Eeckaut (1995) (Tulkens & Vanden Eeckaut, 1995), the MML index is defined in the GBT as follows in equation (4).

$$MML(X^t, y^t, b^t \ , x^{t+1}, y^{t+1}, b^{t+1}) = \frac{1 + \vec{D}^G\ (x^t, y^t, b^t)}{1 + \vec{D}^G(x^{t+1}, y^{t+1}, b^{t+1})} \qquad (4)$$

The directional distance function (DDF) is constructed based on the GBT and can be defined as equation (5):

$$\vec{D}^G(x, y, b) = max\{\beta | (x, y + \beta y, b - \beta b) \in PPS^G\} \qquad (5)$$

An MML productivity index greater than 1 indicates an increase in productivity, while less than 1 indicates a decrease in productivity. Oh also proposed that the MML productivity index can be further decomposed into three components of productivity growth as shown in equation (6). They are EC, BPC and TGC.The decomposition process is shown below:

$$MML(X^t, y^t, b^t \ , x^{t+1}, y^{t+1}, b^{t+1}) = \frac{1 + \overrightarrow{D^G}\ (x^t, y^t, b^t)}{1 + \vec{D}^G(x^{t+1}, y^{t+1}, b^{t+1})}$$

$$= \frac{1 + \overrightarrow{D^t}\ (x^t, y^t, b^t)}{1 + \vec{D}^{t+1}(x^{t+1}, y^{t+1}, b^{t+1})} \times \frac{1 + \overrightarrow{D^I}\ (x^t, y^t, b^t)/1 + \overrightarrow{D^t}(x^t, y^t, b^t)}{1 + \vec{D}^I(x^{t+1}, y^{t+1}, b^{t+1})/1 + \vec{D}^{t+1}(x^{t+1}, y^{t+1}, b^{t+1})}$$

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$$\times \frac{1+\overrightarrow{D^{G}}\,(x^{t},y^{t},b^{t})/1+\overrightarrow{D^{I}}\,(x^{t},y^{t},b^{t})}{1+\vec{D}^{G}(x^{t+1},y^{t+1},b^{t+1})/1+\vec{D}^{I}(x^{t+1},y^{t+1},b^{t+1})} = \frac{TE^{t+1}}{TE^{t}} \times \frac{BPR^{t+1}}{BPR^{t}} \times \frac{TGR^{t+1}}{TGR^{t}}$$

$$= EC \times BPC \times TGC \qquad (6)$$

EC is the index of technical efficiency change, which indicates the catch-up measure of technical efficiency change within a given cluster, reflecting the catch-up benefits of technology in different periods; if EC is greater than 1, it indicates an increase in technical efficiency and the existence of technical catch-up benefits; if EC is less than 1, the opposite is true. BPC is the best frontier change index, which indicates the catch-up measure between the frontier of the decision-making unit within the group and the frontier of the cluster, reflecting the technological progress of each decision-making unit within each group; if BPC is greater than 1, it indicates that the closer the distance between the two, the existence of the technological innovation effect; if BPC is less than 1, it is the opposite. TGC is an index of change in the technology gap ratio, which indicates a measure of catch-up between a given cluster frontier and a common frontier; a TGC greater than 1 indicates that the distance between the two is decreasing and that there is a technology leadership effect; a TGC less than 1 indicates the opposite.

3.2 Selection of indicators and data processing

3.2.1 Selection and description of indicators

The measurement of green TFP in agriculture requires multiple input and output indicators. Based on the criteria of authority, systematicity and accessibility, the selection of indicators is based on the synthesis of previous studies (Gao & Zheng, 2021) (Deng & Yan, 2018) (Zhuo & Zeng, 2018), and labor inputs, agricultural machinery inputs, land inputs, fertilizer inputs, and electricity inputs are selected as input indicators, while the gross agricultural product and agricultural carbon emissions are selected as output indicators.

Input indicators: Labor input is calculated as the number of people employed in agriculture, forestry and fisheries. Agricultural machinery inputs are calculated as the total power of agricultural machinery. Land inputs are measured in terms of the area sown to crops. Fertilizer inputs are calculated as the amount of agricultural fertilizer applied (in pure form). Electricity inputs are calculated as rural electricity consumption.

Output indicator: Desired output is measured as gross agricultural product at constant 2011 prices. Non-desired outputs are generally measured in terms of surface source pollutants such as nitrogen (N), phosphorus (P), or carbon emissions in existing studies, and carbon emissions were used as a non-desired output in this study based on the availability of data.

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The input-output indicator system for green TFP measurement in agriculture is shown in Table 1 below.

Table 1 Input-output indicator system for green total factor productivity in agriculture

norm	Indicator name	variant	unit
Input indicators	labor input	Number of people employed in agriculture, forestry and fisheries	man
	Agricultural machinery inputs	Gross power of agricultural machinery	kilowatt-hour
	land input	Crop sown area	hectares
	Fertilizer inputs	Fertilizer application in agriculture	ton
	Electricity inputs	Rural electricity consumption	Million kWh
Output indicators	Non-expected outputs	Carbon emissions from agriculture	ton
	Expected outputs	Agricultural GDP	ten thousand dollars

Agricultural carbon emissions were calculated by applying the method proposed by Li Bo (Li & Zhang, 2011) with the following formula:

$$E = \sum E_i = \sum T_i \cdot \delta_i \qquad (7)$$

(7) WhereE、Eiand Ti are denoting the total carbon emissions, the carbon emissions from each carbon source and the number of each carbon source, respectively, and δ_i is the emission factor. Table 2 shows the emission coefficients and sources of each carbon source. The carbon emission coefficient of agricultural irrigation needs to be corrected according to Li's practice, and the real carbon emission coefficient of agricultural irrigation in Fujian Province is calculated to be 15.325kg·hm-2.

Table 2 Carbon source coefficients and reference sources for agricultural carbon emissions

carbon source	Carbon emission factor	reference source
fertilizers	0.8956 kg·kg-1	T.o.west、Oak Ridge National Laboratory, USA
agrochemical	4.9341 kg·kg-1	Oak Ridge National Laboratory, USA
agro-film	5.18 kg·kg-1	Institute of Agricultural Resources and Ecological Environment, Nanjing Agricultural University
diesel fuel	0.5927 kg·kg-1	IPCC United Nations Intergovernmental Panel on Climate Change
plow	312.6 kg·km-2	College of Biology and Technology, China Agricultural University
Agricultural irrigation	25 kg·hm-2	Dubey and Lal(2009)

3.2.2 Descriptive statistics and data sources

Table 3 shows the descriptive statistics of each input-output variable. The data for each variable are obtained from the Fujian Statistical Yearbook, the Statistical Yearbook, National Economic Development and Statistical Bulletin of each city in Fujian, and the official website of the Bureau of Agriculture and Rural Affairs (BARA), where missing data are obtained by linear interpolation.

The sample of this study involves nine prefectural-level cities in Fujian Province, and the use of the MML index to measure the green TFP of agriculture in Fujian Province requires that all prefectural-level cities be divided into reasonable clusters, with a certain degree of heterogeneity in the level of agricultural technology between the clusters, and a comparable level of development of the technology of agricultural production in the decision-making units within the clusters. In this study, nine prefectural-level cities in Fujian Province are divided into three clusters based on the "14th Five-Year Plan for Green Agricultural Development in Fujian Province", namely Fuzhou, Xiamen and Quanzhou, Putian, Longyan and Zhangzhou, and Sanming, Ningde and Nanping.

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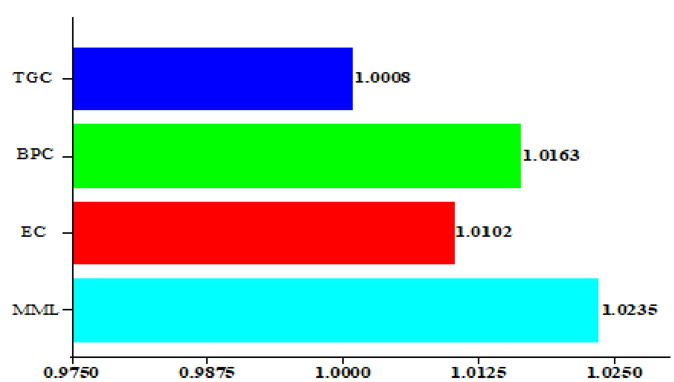
Table 3 Descriptive statistical analysis of variables

variant	unit	average value	standard deviation	minimum value	maximum values
Number of people employed in agriculture, forestry and fisheries	ten thousand people	61.9028	26.3985	7.4296	109.22
Gross power of agricultural machinery	Million kWh	141.1383	64.2254	36.4615	263.3844
Total sown area for agriculture	hectares	207577.2667	107982.4	21691.8667	447339.6
Agricultural fertilizer inputs	ton	127605.4	95952.11	10389	406300
Rural electricity consumption	Million kWh	425031.5	452364.9	20623	1384055
Agricultural GDP	ten thousand dollars	3562797	1767857	413185	7575899
Carbon emissions from agriculture	ton	233316.5	159844.4	17404.72	671541.4

4. Results and Characterization of Green Total Factor Productivity Accounting in Fujian Province Agriculture

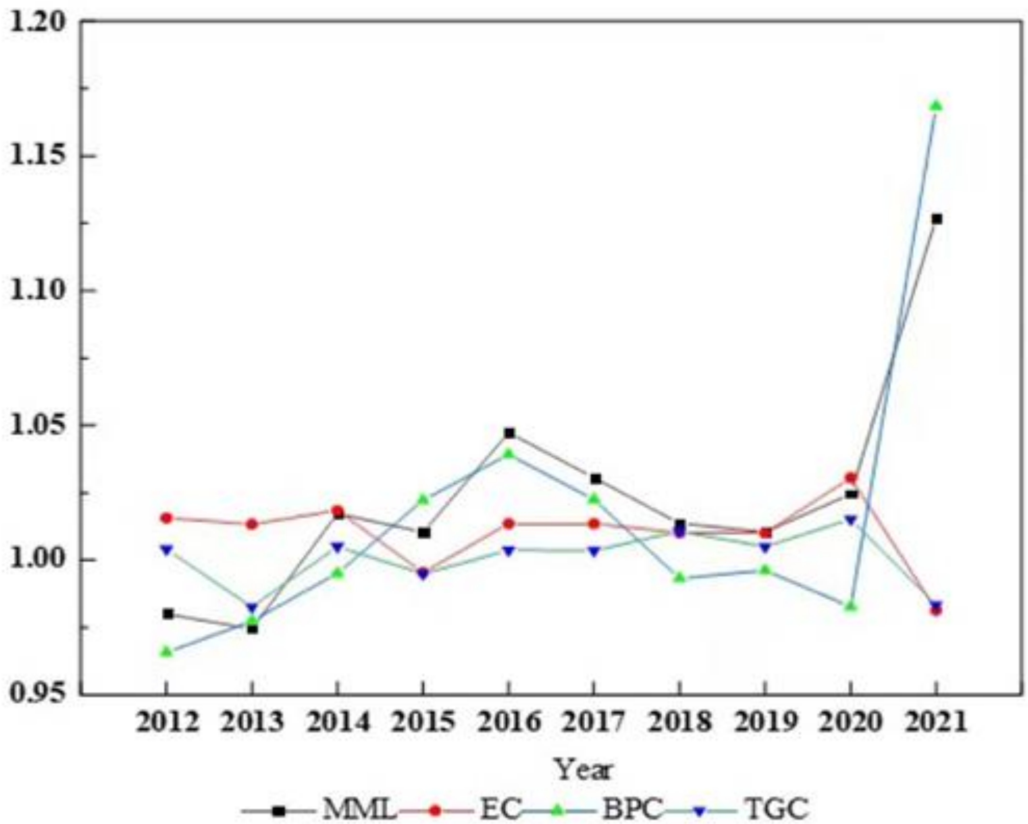
4.1 Results and characterization of the province's green total factor productivity accounting in agriculture

Fig.2 Average MML productivity index and decomposition in Fujian Province, 2012-2021



MaxDEA Ultra 8 was applied to the panel data of nine prefecture-level cities in Fujian Province from 2011 to 2021, and the MML index method was used to measure and decompose the agricultural green TFP, and the MML index and its decomposition in Fujian Province from 2012 to 2021 can be obtained, as shown in Figures 2 and 3. As can be seen from Figure 2, the average MML productivity index of Fujian Province from 2012 to 2021 is 1.0235, indicating that the average annual growth rate of agricultural green TFP in Fujian Province in the past ten years has been 2.35%.The mean values of EC, BPC and TGC are 1.0102, 1.0163 and 1.0008, respectively, which means that the average growth rates of EC, BPC and TGC are 1.02%, 1.63% and 0.08%, respectively, all achieving positive growth. , 1.63%, and 0.08%, all of which realized positive growth, indicating that all three contributed to the growth of agricultural green TFP, with the enhancement of agricultural green TFP brought about by the growth of BPC and EC occupying a dominant position.Reflecting the fact that the increase in agricultural green TFP in Fujian Province in the last decade has mainly come from agricultural technological progress and technological efficiency improvement.

Fig.3 MML Productivity Index and Decomposition, Fujian Province, 2012-2021



According to Figure 3, we can know the change characteristics of agricultural green TFP in Fujian Province in the past ten years. First of all, from 2012 to 2014, the agricultural green TFP in Fujian Province was negative growth, and after 2014, the agricultural green TFP maintained a positive growth trend. As a whole, the agricultural green TFP in Fujian Province shows the trend of increasing, then decreasing and then increasing, in which the lowest point of maintaining positive growth is in 2014 and 2019, which is only 1.03% to 1.05%; the highest point is in 2021, which reaches 12.7%.Although the green TFP of agriculture maintains a positive growth rate from 2017 to 2019, the growth rate shows a decreasing trend, which may be due to an overall imbalance in the agricultural structure caused by the excessive pursuit of rapid industrialization and increased food production during the 13th Five-Year Plan period, and an imbalance in the structure of the agricultural industry will affect the efficiency of agricultural production. In addition, Fujian Province is a serious typhoon disaster area. According to the statistics of the Fujian Provincial Climate Center, in the past 60 years, 53 typhoons have made landfall in Fujian Province, causing great economic losses to the agriculture in Fujian Province. Starting from 2020, the growth rate of agricultural green TFP in Fujian Province shows an upward trend. With the green and sustainable transformation of agricultural development and the gradual achievement of structural reform of the agricultural supply side, the structure of agricultural production has been adjusted, the establishment of the red line of permanent basic farmland, the introduction of various regulations on agricultural protection and the improvement of related policies and regulations have made the internal and external conditions of agricultural production to be improved to a certain extent.

Second, from the three curves of EC, BPC and TGC in Figure 3, we can know that the index of change of the technology gap ratio, TGC, is basically unchanged from 2012 to 2021, and maintained at the level of 1, which indicates that the gap between the level of agricultural production technology in each region of Fujian Province and the level of production technology in the common frontier is narrowing at a slow pace, but the technological leadership effect that it generates is relatively weak. The technical efficiency change index EC basically stays at a level greater than 1 and shows a relatively smooth trend, maintaining at the level of 1.0102, indicating that the contribution of agricultural technology efficiency improvement to agricultural green TFP growth is relatively stable. The mean value of the optimal frontier change index BPC is the highest, 1.0163, which is consistent with the trend of the MML productivity index curve, and the lowest and highest points appear in the same year, indicating that agricultural technology progress and innovation play the most important role in the growth of agricultural green TFP in Fujian Province, and the two may influence each other. The above analysis shows that the growth of agricultural green TFP in Fujian Province mainly relies on the progress of agricultural technology and the improvement of agricultural technology efficiency.

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4.2 Results and characterization of green total factor productivity in agriculture in the subregion

Table 4 shows the MML productivity index and its decomposition results obtained after dividing the nine prefectural-level cities in Fujian Province into three clusters, based on which the measurement results can be further analyzed to characterize the green TFP of agriculture in the following three sub-districts and the main sources of driving force that contribute to its growth.

Table 4 Zonal MML productivity index and its decomposition

	Fuzhou, Xiamen, Quanzhou Division				Zhangzhou, Longyan, Putian Division				Sanming, Nanping, Ningde Division			
vintages	MML	EC	BPC	TGC	MML	EC	BPC	TGC	MML	EC	BPC	TGC
2012	0.9754	1.0486	0.9268	1.0122	0.9983	1.0118	0.9697	1.0176	0.9662	0.9865	1.0005	0.9824
2013	1.0171	1.0011	1.0116	1.0043	0.9994	0.9994	1.0046	0.9956	0.9069	1.0394	0.9160	0.9479
2014	1.0532	1.0468	0.9806	1.0284	1.0058	1.0032	1.0072	0.9960	0.9928	1.0053	0.9976	0.9907
2015	1.0442	0.9643	1.0837	0.9992	1.0138	0.9815	1.0336	0.9995	0.9730	1.0405	0.9495	0.9860
2016	1.0510	0.9955	1.0784	0.9833	1.0548	0.9808	1.0511	1.0347	1.0363	1.0643	0.9881	0.9931
2017	1.0234	1.0324	0.9828	1.0154	1.0594	1.0747	0.9961	1.0018	1.0090	0.9337	1.0886	0.9934
2018	1.0231	1.0072	0.9964	1.0197	1.0037	0.9996	1.0035	1.0009	1.0139	1.0235	0.9798	1.0114
2019	1.0017	0.9812	1.0043	1.0167	1.0207	1.0458	0.9779	0.9985	1.0090	1.0032	1.0064	0.9997
2020	1.0300	0.9989	1.0182	1.0136	1.0118	1.0117	0.9992	1.0016	1.0317	1.0812	0.9306	1.0302
2021	1.1583	1.0046	1.1407	1.0106	1.1457	0.9760	1.1845	0.9908	1.0767	0.9634	1.1800	0.9486
average value	1.0377	1.0081	1.0224	1.0103	1.0313	1.0084	1.0227	1.0037	1.0015	1.0141	1.0037	0.9883

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4.2.1 Characterization of green total factor productivity in agriculture in Fuzhou, Xiamen and Quanzhou subregions

As shown in Table 4, the average MML index of Fuzhou, Xiamen and Quanzhou sub-region in the past ten years is 1.0377, which means that the average annual growth of agricultural green TFP in this region is 3.77%. From 2012 onwards, the MML productivity indexes of this region are all greater than 1, indicating that its agricultural green TFP has been maintaining positive growth, and the change trend is similar to that of the provincial agricultural green TFP, which shows a trend of increasing, then decreasing and then increasing.The mean values of EC, BPC, and TGC are 1.0081, 1.0224, and 1.0103, respectively. Among them, BPC has the highest average annual growth rate of 2.24%, while EC and TGC have average annual growth rates of 0.81% and 1.03%, respectively.The highest average annual growth rate of BPC indicates that the municipalities within the subcluster have a close proximity between the technological frontiers of agricultural production and the production frontiers of the cluster, and that the largest contributor to the growth of green TFP in agriculture is the technological advances in agriculture brought about by BPC, and that this region's agricultural science and technology innovation level is high and there is a rich innovation effect. The average annual growth rate of TGC is 1.03%, indicating that the distance between the technological frontier and the common frontier in this subregion decreases, i.e., the level of agricultural production technology is close to the level of production technology in the common frontier, and there is a good technological leadership effect.The average annual growth rate of EC is 0.81%, reflecting the fact that the improvement of the efficiency of agricultural technology in this subregion also plays a certain role in the growth of green TFP in agriculture, but it is more secondary. The higher level of agricultural green TFP and agricultural production technology in this subregion is due to the first tier of economic development, which provides more complete supporting facilities for agricultural production, builds more platforms for agricultural technological innovation, and injects more human resources and financial inputs.

4.2.2 Characterization of green total factor productivity in agriculture in Zhangzhou, Longyan and Putian subregions

As shown in Table 4, the average MML productivity index of Zhangzhou, Longyan and Putian sub-districts is comparable to that of Fuzhou, Xiamen and Quanzhou sub-districts, which is 1.0313, i.e. the average annual growth rate of agricultural green TFP is 3.13%. Since 2013, the agricultural green TFP have all been positively growing, and the changes are consistent with the above, showing a trend of first increasing, then decreasing and then increasing again.The mean values of EC, BPC, and TGC are 1.0084, 1.0227, and 1.0037, i.e., the average annual growth rates of EC, BPC, and TGC are 0.84%, 2.27%, and 0.37%, respectively.The annual average of BPC's growth rate is the highest, indicating that the largest contributing factor to the growth of

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agricultural green TFP in this subregion is consistent with the Fuzhou, Xiamen, and Quanzhou subregions, and comes from agricultural technological progress. In terms of EC and TGC, unlike Fuzhou, Xiamen, and Quanzhou subregions, the average annual growth rate of EC in Zhangzhou, Longyan, and Putian subregions is higher than that of TGC, at 0.84%, but is close to that of Fuzhou, Xiamen, and Quanzhou subregions, at 0.81%; while the growth rate of TGC, at 0.37%, is much lower than that of Fuzhou, Xiamen, and Quanzhou subregions, at 1.03%. The growth rate of TGC indicates that the distance between the technological frontier and the common frontier in this subregion is gradually and slowly decreasing, but the technological leadership effect is weak. The economic development level of this sub-region belongs to the second echelon in Fujian Province, and both the situation of agricultural development and the innate agricultural production conditions have certain advantages relative to cities such as Ningde, so the agricultural green TFP of this sub-region is also maintained at a high level.

4.2.3 Characterization of green total factor productivity in agriculture in Sanming, Nanping and Ningde sub-districts

The comparative analysis in Table 4 shows that the agricultural green TFP of Sanming, Nanping and Ningde sub-districts is much lower than that of the previous two sub-districts, with an average MML productivity index of 1.0015,and an average annual growth rate of only 0.15%, and the positive growth of the agricultural green TFP was not realized until 2016, but the MML productivity index is gradually rising and growing at a fast rate, which indicates that there is still great room for improvement and development potential.The mean values of EC, BPC, and TGC are 1.0141, 1.0037, and 0.9883, respectively, which means that the average annual growth rates of EC, BPC, and TGC are 1.41%, 0.37%, and -0.0117%, respectively. Unlike the previous two sub-regions, this sub-region has the highest growth rate of EC and the highest growth rate of BPC in the previous two sub-regions, indicating that the main reason for the growth of green TFP in agriculture in this sub-region is the benefit of technological catch-up from EC growth, i.e., it comes from the improvement of technological efficiency in agriculture. The growth rate of BPC is 0.37%, which indicates that the distance between the technological frontiers of agricultural production and the cluster production frontiers of the municipalities within the subcluster is narrowing, and the agricultural production technology has been improved to some extent.The average annual growth rate of TGC is -0.0117%, which indicates that the technological frontiers of this subcluster are becoming more and more remote from the global technological frontiers, and that the level of the agricultural production technology is becoming more and more remote from the production of the common production frontiers. technology level is getting farther and farther away from each other, and there is no technology leadership effect. It is worth mentioning that the green TFP of agriculture in this sub-district during 2012-2013 and 2014-2015 is low, and the MML productivity index is only about 0.90. According to the relevant

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information query, it can be found in the Ningde Statistical Yearbook that the rural electricity consumption in 2012 was 1281.92 million kWh, in 2013 and 2014 it was 290.609 million kWh and 306.499 million kWh, and in 2015 the rural electricity consumption was 512.550 million kWh. The reason for the huge increase in rural electricity consumption is that the operation of the first Unit 1 of the Ningde Nuclear Power Plant in 2013 greatly increased the demand for electricity supply in Ningde City, which, together with the commissioning of the subsequent units, has brought sufficient supply of electricity and energy to various industries. As a result, the sharp spike in rural electricity consumption in Ningde City in these two years resulted in a large change in the electricity input indicator and a small change in the other indicators, leading to a lower measurement of the MML productivity index in these two years, but this situation still does not affect the result that the level of green TFP in agriculture in this subregion is low and relatively lagging behind that of the previous two subregions.

4.3 Results and characterization of green total factor productivity in agriculture by prefecture and municipality

Table 5 below reflects the average agricultural green TFP and its decomposition of nine prefecture-level cities in Fujian Province in the recent decade. From the MML productivity index, the average annual growth rate of agricultural green TFP in Fuzhou, Putian, Longyan, Quanzhou, Xiamen, Sanming, and Zhangzhou in the past ten years is positive, in which the average annual growth rate of agricultural green TFP in the five cities of Fuzhou, Putian, Longyan, Quanzhou, and Xiamen is higher than the overall average level of 2.35%, and the average annual growth rate of agricultural green TFP in Putian and Quanzhou is the highest, respectively 4.65% and 4.42%, the above analysis shows that the cities with higher agricultural green TFP are mainly concentrated in coastal areas. The average annual growth rate of agricultural green TFP in Sanming, Zhangzhou, Nanping and Ningde is lower than the overall average, and the average annual growth rate of agricultural green TFP in Nanping and Ningde is negative, at -0.02% and -0.99% respectively.

Table 5 Average MML productivity index and its decomposition for 9 cities in Fujian Province

CITY	MML	EC	BPC	TGC
Fuzhou	1.0366	0.9977	1.0257	1.0184
Putian	1.0465	1.0224	1.0313	0.9996
Longyan	1.0385	1.0198	1.0095	1.0107

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Quanzhou	1.0442	1.0186	1.0350	0.9916
Xiamen	1.0324	1.0078	1.0064	1.0210
Sanming	1.0148	1.0259	0.9961	0.9977
Zhangzhou	1.0091	0.9831	1.0274	1.0009
Nanping	0.9998	1.0255	0.9835	0.9984
Ningde	0.9901	0.9908	1.0315	0.9689
average value	1.0235	1.0102	1.0163	1.0008

In terms of the technical efficiency change index EC: the average growth rate of EC is 1.02%, and the average growth rate of EC in Putian, Longyan, Quanzhou, Sanming, and Nanping are all higher than the overall average. Among them, the improvement of agricultural technical efficiency in Putian and Quanzhou has an important role in the improvement of agricultural green TFP, but the biggest contribution to the improvement is the agricultural technical progress brought by the growth of the best frontier change index BPC. The agricultural green TFP enhancement in Longyan, Sanming, and Nanping mainly comes from the agricultural technology efficiency enhancement brought by the growth of the technology efficiency change index EC, which narrows the gap between the technical frontiers of agricultural production in each place and the frontiers of each subdistrict cluster. Fuzhou, Xiamen, Zhangzhou, and Ningde all have lower than average EC growth rates, and the contribution of EC to agricultural green TFP growth is not the most dominant, except in Xiamen, where EC growth is negative and there is no technological catch-up benefit.

In terms of the best frontier change index BPC: BPC improvement is the main reason for agricultural green TFP growth in most cities. Except for Sanming and Nanping, the growth rate of the best frontier change index BPC is positive in all other cities and basically serves as the main source of agricultural green TFP growth, indicating that the improvement of the level of agricultural production technology and the improvement of the level of agricultural production technology plays a very important role in the growth of agricultural green TFP, reflecting the fact that agricultural scientific and technological innovation is the most effective driving force for the improvement of agricultural green TFP. The agricultural green TFP and BPC of Sanming and Nanping are both lower than the average level, indicating that lower agricultural green TFP also corresponds to lower agricultural production technology level. Therefore, the growth of agricultural green TFP in Sanming and Nanping temporarily relies on the improvement of agricultural technical efficiency brought about by the technical efficiency change index EC, indicating that there is still some room for improvement in the agricultural development of

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Sanming and Nanping.

In terms of the technology gap ratio change index, TGC: the impact of TGC on the green TFP of agriculture in most cities and municipalities in Fujian Province is still at an early stage and is relatively weak. the average level of TGC is 1.0008, with an average annual growth rate of only 0.08%. Only Fuzhou, Xiamen, Zhangzhou and Longyan realized positive growth in TGC. Among them, the average annual growth rate of TGC in Xiamen is 2.1%, which is larger than the average annual growth rate of EC and BPC, indicating that the growth of green TFP in agriculture in Xiamen region mainly comes from the technological leadership effect brought about by the narrowing of the distance between the cluster agricultural production technological frontiers and the global agricultural production technological frontiers, while the increase in the efficiency of agricultural technology and technological improvement and innovation brought about by the growth of EC and BPC play an important role. The technological leadership effect of TGC growth in Fuzhou, Zhangzhou and Longyan plays a certain role in the growth of agricultural green TFP, and the promotion effect of EC or BPC growth on agricultural green TFP still occupies a dominant position.

5. Conclusions and recommendations

5.1 Conclusions of the study

Based on the Metafrontier Malmquist-Luenberger index model, this study accounts for the panel data of nine prefectural-level cities in Fujian Province from 2011 to 2021, and finally measures the agricultural green total factor productivity of Fujian Province at the provincial level, sub-districts, and municipalities, and discusses the driving factors and evolutionary characteristics of the agricultural green total factor productivity in Fujian Province. productivity's driving factors and evolutionary characteristics, and the conclusion of the study shows that:

First, at the provincial level, agricultural green total factor productivity in Fujian Province has basically maintained a positive growth trend in the past decade, with an average annual growth rate of 2.35%. Its growth momentum mainly comes from agricultural technology progress and agricultural technology efficiency improvement, that is, the innovation effect and technology catching-up benefit is obvious, while the technology gap change brought about by the narrowing of the technology gap between the cluster technology frontier and the common benchmark technology frontier plays a certain role in the agricultural green total factor productivity improvement, but the impact is relatively weak.

Second, at the subregional level, there are imbalances and differences in the growth rate and growth dynamics of agricultural green total factor productivity in each subregion. Fuzhou, Xiamen, Quanzhou sub-districts and Zhangzhou, Longyan, Putian sub-districts have faster growth rates of agricultural green total factor productivity, whose main contribution comes from the progress and improvement of agricultural technology, and the innovation effect is more obvious, and all of them have technological catching-up benefits and technological leadership effects; Sanming, Nanping, Ningde sub-districts have the improvement of agricultural green total factor productivity mainly coming from agricultural technological efficiency enhancement brought by technological catch-up benefits, and the innovation effect brought by the progress of agricultural technology has not dominated, while the technological leadership effect does not exist. The innovation effect brought by technological progress is not yet dominant, and the technological leadership effect does not exist.

Third, at the prefecture and city levels, the green total factor productivity of agriculture in all cities has basically realized positive growth, and the rate of growth is relatively stable. In terms of the quality of growth and the source of growth momentum, technological progress and innovation in agricultural production play a major or important role in the improvement of agricultural green total factor productivity in all nine cities; the improvement of agricultural technological efficiency is the main driving force for the improvement of agricultural green total factor productivity in the inland cities; the technological leadership effect brought about by changes in technology gaps exists almost exclusively in the more economically and agriculturally developed cities and the effect of technological leadership is weaker than the effect of technological efficiency and technological progress. The technological leadership effect is almost exclusively found in the more economically and agriculturally developed cities, and it is weaker than the effect of technological efficiency and progress.

5.2 Policy recommendations

In response to the above conclusions, the following recommendations are given:

First, maintain the favorable trend of agricultural green total factor productivity development in Fujian Province and continue to promote the green transformation of the agricultural development mode in Fujian Province. Since the driving force for the growth of agricultural green total factor productivity in Fujian Province mainly comes from the improvement of agricultural technology efficiency and technological progress, efforts should be made to improve the efficiency of agricultural technology and the innovation level of agricultural technology, especially the innovation of green technology. Firstly, we should promote agricultural science and technology innovation capacity by improving agricultural R&D investment, sounding relevant policies and regulations and building platforms for government, industry, academia and research. Secondly, it is necessary to improve the intellectual property rights system of agricultural scientific and technological innovation achievements and the system of popularizing and transforming the achievements, to protect the enthusiasm of talents' scientific and

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technological innovation activities and to promote the popularization and application of new agricultural production technologies. Furthermore, strengthen the construction of agricultural science and technology innovation team, train a group of agricultural science and technology innovation pioneers, improve the treatment of scientific and technological innovation talents, improve the incentive mechanism for technological innovation, and provide talent protection for agricultural science and technology innovation.

Secondly, to promote the balanced and rational development of green total factor productivity in agriculture in all regions of Fujian Province, and to strengthen the exchange of agricultural production cooperation among regions. First of all, we should promote the flow of talents and funds between regions and cities, the promotion of advanced green production technology and the exchange and cooperation of similar production areas and complementary advantages through the establishment of cross-region agricultural development cooperation mechanisms, forming both win-win and benign competition layout between regions, such as agricultural machinery technology exchange and cooperation stations and cross-region service cooperatives for agricultural machinery, etc.; second, we need to improve the relevant policy system and guarantee system of cross-region cooperation, in order to promote the Secondly, it is necessary to improve the relevant policy system and guarantee system of inter-regional cooperation, in order to promote the high-quality development of agriculture in various regions.

Thirdly, localities should clearly define their own development functions, combine their own level of development, agricultural industrial structure, resource endowment and ecological governance with other factors, and take the road of green and sustainable development of agriculture in accordance with local conditions, so as to form the backbone of promoting stable growth in the total factor productivity of green agriculture. Cities with a higher level of economic development and better agricultural development can further improve agricultural infrastructure facilities, increase the innovation rate and utilization rate of agricultural green production technology, promote the integration of the three industries, and continue to promote the structural reform of the agricultural supply side. Cities with an average level of economic development and agricultural development, constrained by the external environment and economic strength of agricultural production, can develop leisure and tourism agriculture, modern eco-agriculture and other specialties on the basis of their own good ecological foundations, and take the path of green and sustainable development to realize a sustainable increase in green total factor productivity in agriculture.

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Reference

[1] GUO H.H., LIU X.M.(2021). Spatio-temporal divergence and convergence of green total factor productivity in Chinese agriculture[J]. Quantitative and Technical Economic Research,38(10):65-84.

[2] GAN T.Q., DU J.G., LI B.(2022). Divergent characteristics and driving factors of agricultural total factor productivity in Chinese counties[J]. Economic Issues, (04):101-107.

[3] Liu C.K.(2021). Rural population aging and regional heterogeneity in agricultural total factor productivity[J]. Journal of South China Agricultural University (Social Science Edition), 20(6):46-55.

[4] Liu Y.W., Ouyang Y., Cai H.Y.(2021). A study on total factor productivity measurement and spatial and temporal evolution characteristics of green agriculture in China[J]. Research on Quantitative and Technical Economics, 38(05):39-56.

[5] LIN Q.N., MAO S.P.(2023). Evolutionary process, measurement method and future outlook of total factor productivity in agriculture[J]. Journal of China Agricultural University, 28(04):248-256.

[6] He Y.Q.(2004). Measurement and Analysis of the Contribution Rate of Agricultural Technology Progress in Jiangxi[J]. Journal of Jiangxi University of Finance and Economics, (6):45-47.

[7] FAN S.G., ZHANG X.B.(2002). Production and productivity growth in Chinese agriculture: New na-tional and regional measures[J].Economic Development and Culture Change, 50(4):819-838.

[8] Liu L., Zhang W.A.(2017). Agricultural Total Factor Productivity Growth and Spatial Spillover Effects in China - An Empirical Analysis Based on the Data of 31 Provinces and Municipalities from 2000 to 2014[J]. Western Forum, 27(06):49-57.

[9] Liu H., Wang Z., Jiang S.(2015). Research on total factor productivity growth in agriculture based on stochastic frontier production function[J]. Exploration of Economic Issues, (11):35-42.

[10] Quan J.Z.(2009). Empirical analysis of total factor productivity growth in China's agriculture:1978-2007--Based on stochastic frontier analysis (SFA)[J]. China Rural Economy, (09):36-47.

[11] Fan L.X., Li G.C.(2012). Total factor productivity and its research progress in agriculture[J].

Contemporary Economic Science, 34(01):109-119+128.

[12] YIN C.J., LI G.C., LU Y.(2014). Dynamic evolution mechanism of total factor productivity growth distribution in Chinese agriculture[J]. Statistics and Information Forum, 29(3):53-58.

[13] Du J.(2015). Total factor productivity growth and its spatio-temporal differentiation in Chinese agriculture[J]. Research Management, 36(05):87-98.

[14] Liu Z.W.(2015). Total factor productivity growth and decomposition of Chinese agriculture under resource and environmental constraints[J]. Research on Science and Technology Management, 35(01):83-87.

[15] Min R., Li G.C.(2012). The growth and decomposition of China's food total factor productivity under environmental constraints--an observation based on provincial panel data and serial Malmquist-Luenberger index[J]. Economic Review, (05):34-42.

[16] Oh DH. (2010).A meta-frontier approach for measuring an environmentally sensitive productivity growth in-dex. Energy Economics (32):146~157.

[17] Chen H.L., Qin W.F.(2014). Inclusive growth of the Chinese economy:An explanation based on the perspective of inclusive total factor productivity[J]. China Industrial Economy, (01):18-30.

[18] Chung YH, Färe R, Grosskopf S (1997). Productivity and undesirable outputs: a directional distance functionapproach. J Environ Manag 51:229–240.

[19] Du L., Tian M.H., Ma S. et al.(2022). Measurement and evolutionary characterization of total factor productivity in Chinese agriculture - empirical evidence based on 283 prefecture-level cities in China[J]. Journal of Sichuan Agricultural University, 40(04):619-624.

[20] Tulkens H, Vanden Eeckaut P (1995). Non-parametric efficiency, progress and regress measures for p-anel data:methodological aspects. Eur J Oper Res 80:474–499.

[21] Gao M.F., Zheng J.(2021). Measurement of total factor productivity in Chinese agriculture and its analysis of spatial and temporal variations: a reexamination based on the perspective of carbon sinks[J]. Ecological Economy, 37(12):98-104+120.

[22] Deng X.L., Yan W.B.(2018). Research on the impact of rural infrastructure on agricultural total factor productivity[J]. Research on Finance and Trade ,29(04):36-45.

[23] Zhuo L., Zeng F.S.(2018). Impact of rural infrastructure on total factor productivity of food[J]. Agricultural Technology and Economics, (11):92-101.

ISSN: 2455-8834

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[24] LI B., ZHANG J.B., LI H.P.(2011). Spatial and temporal characteristics of agricultural carbon emissions in China and decomposition of influencing factors[J]. China Population Resources and Environment, 21(08):80-86.

