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Agricultural Carbon Emission Efficiency Measurement, Space Spillover and Influencing Factors

-- The SBM Super-Efficiency Model Based on the Undesired Output

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Abstract

Under the background of "double carbon", studying provincial agricultural carbon emission efficiency has important strategic significance to agricultural carbon emission reduction and promoting the transformation of low-carbon agriculture. The undesired output SBM model was used to calculate the agricultural carbon emission and agricultural carbon absorption from 2012 to 2022 in Chinese mainland 30 provinces, municipalities and autonomous regions other than Hong Kong, Macao, Taiwan and Tibet, and then calculate the agricultural carbon emission efficiency of each province and city. The study shows that the overall agricultural carbon emission efficiency in China is increasing, with the northern coastal areas being the highest and the middle reaches of the Yangtze River having the lowest agricultural carbon emission efficiency. Based on this, the provinces should implement differentiated agricultural carbon emission reduction strategies to further enhance the agricultural emission reduction and increase efficiency capacity in China, promote the sustainable development of provincial agriculture, and promote the high-quality development of low carbon agriculture.

Keywords

Carbon emission efficiency; space overflow; SBM ultra-efficiency model.

1. Introduction

In recent years, with the steady development of the economy, the expectation of the "two-carbon" plan, strengthening energy security, enhancing the international image, promoting economic development and grasping the carbon emission right has increasingly become an important strategic plan for China to step on the international stage. However, the realization of "carbon neutrality" is agricultural resources. Agriculture is one of the important sources of carbon emissions. The carbon dioxide emissions of agriculture and food systems exceed 30% of the global total amount of man-made emissions, and the carbon emissions caused by agricultural production activities cannot be underestimated. How to effectively measure the efficiency of agricultural carbon emission, analyze the spatial spillover and influencing factors of agricultural carbon emission to explore the path of collaborative improvement, further enhance the ability of agricultural emission reduction and efficiency increase in China, and promote the sustainable development of provincial agriculture has become an urgent problem to be solved in this paper.

Agricultural carbon emission efficiency includes the economic benefit or crop output produced per unit of carbon emission in agricultural production activities. This concept is often used in various studies to measure the efficiency and sustainability of agricultural production in terms of carbon emissions, and it is an important indicator to assess the environmental impact of agricultural production methods. In agricultural production activities, agricultural carbon

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emissions are due to greenhouse gas emissions from the use of traditional agricultural production materials such as fertilizers, pesticides, agricultural film and diesel [1]. Existing scholars on the basis of fossil fuel energy consumption data, fertilizers, pesticides, agricultural carbon emissions source coefficient, based on the IPCC carbon emissions source coefficient, some scholars use the life cycle method (LCA) agricultural production activities of carbon emissions and the whole life cycle of agricultural carbon emissions. By ating the source coefficient of agricultural carbon emissions such as chemical fertilizer, pesticide, agricultural film and diesel oil, Tian Yun and Yin Min Hao calculated agricultural carbon emissions on the basis of the life cycle evaluation model from four aspects, and found that China's agricultural carbon emissions were fluctuating and had provincial differences [2]. Some scholars have further used SFA and DEA to calculate the efficiency of agricultural carbon emissions, and further explored the regional differences and spatial and temporal distribution changes of agricultural carbon emissions.

Around the research topic of this paper, some scholars at home and abroad have explored this. There are three types of related literature: one is the research on agricultural carbon emission; the second is the spatial overflow of agricultural carbon emission; and the third is the research on the influencing factors of agricultural carbon emission. However, the existing literature has only considered the individual overall influencing factors of efficiency when measuring the efficiency of agricultural carbon emissions, often ignoring its spatial spillover effect. In this paper, the main marginal contribution is: study agricultural carbon emission based on the perspective of agricultural carbon emission efficiency, space overflow and intermediary effect, construct a comprehensive index system and analysis framework; measure the agricultural carbon emission by undesired output method; finally, test the efficiency of super-efficiency SBM model, and use the spatial measurement method to explore the convergence of regional interprovincial differences. From the triple perspective of agricultural carbon emission efficiency measurement, spatial spillover effect and intermediary effect, [3], measure agricultural carbon emission, aiming to improve the low carbon effect of overall agriculture, improve ultra-efficiency emission, and provide beneficial practical guidance and practical policy suggestions for emission reduction, efficiency increase and high-quality development of low-carbon agriculture in China.

2. Theoretical mechanism and research hypotheses

2.1. Model construction

Ultra-efficiency SBM model Because the efficiency value calculated by CCR and BCC model tends to overestimate the decision unit, and the efficiency value calculated by SBM model is less than the efficiency value calculated by the traditional model, so the SBM model is more accurate [4]. The model enables further analysis of the decision units with an efficiency value of 1 on the basis of the existing SBM model. Suppose there are n decision units (DMUs), each DMU has m input variables x, s1 expected output variable yg, s2 unexpected output variables yb. For the k th DMU, the input variable vector is xk, the expected output variable vector is ygk, and the unexpected output variable vector is ybk. The SBM hyper efficiency model defining undesired output is the SBM hyper efficiency model defining undesired output is [5]:

$$\min\ \rho = 1 - 1m\sum i = 1msi - xikl + 1s1 + s2(\sum i = 1s1sigyik + \sum i = ls2sibyik) \tag{1}$$

Space dubin model traditional linear regression model may ignore spatial factors cause error, space dubin model different from ordinary panel regression model, can consider the spatial correlation between nearby area [3], this paper studies the influence of variable agricultural carbon efficiency of space spillover effect, so the building space dubin model as follows in [6]:

$$Y = \rho WY + \beta X + \theta WX + \alpha + \varepsilon \tag{2}$$

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Where, Y is the dependent variable agricultural carbon emission efficiency, X is the influence factor of the independent variable agricultural carbon emission efficiency, ρ, β, θ is the regression coefficient, W is the spatial distance matrix, α and ε are the constant term and random interference term. In this paper, the influencing factors of agricultural carbon emission efficiency are determined from the following seven aspects, the selection of influencing factors of agricultural carbon emission efficiency and the descriptive statistical results are shown in Table 1.

Mediation Effect The mediation effect model was selected for empirical testing to test the direct and indirect effects of different factors on agricultural carbon emission efficiency, as well as the interaction effects between different factors. The following model is designed and tested:

$$MA_{it} = a_0 - a_1 MA_{it-1} + a_2 DE_{it} + a_3 KZBL_{it} + \lambda_i + \eta_t + \varepsilon_{it} \tag{3}$$

Is the core DE_{it} explanatory variable W_{it} and the $KZBL_{it}$ mediating variable, which represents the effect of the control variable. Specifically, respectively examines the following several aspects of intermediary effect: (1) the influence of agricultural structure on agricultural carbon efficiency through agricultural input intensity and agricultural environmental quality factors (2) the intensity of agricultural carbon efficiency through agricultural production scale and agricultural technology level and other factors play a role. Confidence intervals for the mediation effects were estimated using the Bootstrap method and tested for significance. According to the results of mediation effect analysis, the differences and characteristics of different factors on agricultural carbon emission efficiency, as well as the existing problems and difficulties.

2.2. Research hypothesis

Differences of time and space in different regions have a significant impact on their carbon emission efficiency. Different degrees of development between provinces, and other differences in agricultural structure and agricultural input intensity. When the level of agricultural development in a certain region is at a high level, the degree of its agricultural development will affect other provinces. Based on the above analysis, the research hypothesis 1 is proposed:

H1: There is a spatial spillover effect between provinces, and all provinces should develop together to narrow the gap between urban and rural areas.

Direct Impact of Agricultural Structure and Agricultural Investment intensity on Low-carbon Agriculture and High-quality Agricultural Development It is mentioned in Lewis' dual economic structure model that the surplus labor force in rural areas will gradually shift to non-agricultural industries. The transfer of rural labor force leads to the phenomenon of farmers increasing agricultural materials in order to ensure that agricultural output is not reduced, which then affects the efficiency of agricultural carbon sink. Optimizing the agricultural structure, reducing the proportion of animal husbandry and increasing the proportion of plant-based food can effectively improve the rate of agricultural carbon emissions. Based on the above analysis, the research hypothesis 2 is proposed:

H2: Optimizing the agricultural structure and increasing the intensity of agricultural input can contribute to carbon emission reduction.

Indirect Impact of Agricultural Structure and Agricultural input intensity on low-carbon development of high-quality Agriculture With the expansion of agricultural production scale and intensity, the carbon emissions in agricultural activities will increase accordingly. The different agricultural structure will also have different impacts on the agricultural carbon emission rate. Optimizing the agricultural structure and reducing the proportion of animal husbandry can improve the agricultural carbon emission rate. Based on the above analysis, the research hypothesis 3 is proposed:

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H3: The influence of agricultural structure on agricultural carbon emission efficiency plays a role through factors such as agricultural input intensity and agricultural environmental quality

In agricultural input, the larger the scale of agricultural production, the greater the intensity of agricultural input. Agricultural input will have some impact on agricultural carbon emissions. The density of agricultural machinery is expressed by the ratio of the total power of agricultural machinery to the total sown area of crops. The increase of agricultural machinery density will lead to [7] increase of non-expected output in agricultural production, which will affect the efficiency of agricultural carbon sink. Based on the above analysis, we propose the research hypothesis 4:

H4: The influence of agricultural input intensity on agricultural carbon emission efficiency plays a role through factors such as agricultural production scale and agricultural technology level

3. Study Design

3.1. Variable selection and data sources

Interpreted variables: Agricultural carbon emissions Agricultural carbon emissions consof the absolute amount of carbon emissions from planting industry and carbon emissions from livestock and poultry breeding. The emissions of each carbon source can be estimated by a specific calculation formula and then added up to obtain the total agricultural carbon emissions, as shown in the formula:

$$AC = \sum_{i=1}^{n} e_i \times a_i \tag{4}$$

In the formula AC, it is agricultural e_i carbon emissions, which is the carbon emission coefficient of [5], respectively, irrigation of pesticides a_i, fertilizer, diesel, tillage, n livestock and poultry breeding (cattle (non-cow), sheep, cow), and the activity level of each carbon source e_i, and the number of types of carbon sources. For each carbon source, we determined the emission coefficients based on the experimental data or the standard values provided in the literature.

Table 1. Various carbon sources and their emission coefficients

carbon source	Carbon emission coefficient	Reference source
pesticide	4.93kg/kg	And Oak Ridge National Laboratory, USA
chemical fertilizer	0.89kg/kg	And Oak Ridge National Laboratory, USA
irrigate	266.48kg/hm^3	Duan Hua equality
diesel oil	0.5927kg/kg	IPCC
turn over	312.60kg/hm^3	Lee wave
Cattle (non-cows)	1731.00kg/ (First * year)	
sheep	271.30kg/ (First * year)	Hu Xiangdong et al
dairy cattle	2398.00kg/ (First * year)	
hog	270.40kg/ (First * year)	

Core explanatory variables: Agricultural Public Investment (PI) In the SBM ultra-efficiency model based on undesired output, agricultural investment (PI) is generally considered as a key factor affecting the efficiency of agricultural carbon emissions. This is based on public

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investment to improve agricultural infrastructure and promote technological innovation and application, thus improving agricultural production efficiency and reducing carbon emissions.

Intermediary variables Agricultural structure and agricultural input intensity are selected in this paper. As an intermediary variable, in order to maintain the comprehensiveness and availability of sample data, all kinds of energy consumption data involved in carbon emissions are derived from the [8] and EPS Global Statistical Data Platform of China Energy Statistics Yearbook 2012-2022.

4. Empirical Research

4.1. Results and Analysis

China's agricultural carbon emission rate 2012-2022, China's carbon emissions showed a significant growth trend, the five provinces accounted for more than one third (36.65%) of the national total carbon emissions, while the five provinces with the smallest carbon emissions accounted for less than 5% of the country; provinces also have significant differences, between 3.94 tons and 33.29 tons. This reflects differences in economic development, energy mix and energy efficiency among provinces.

Spatial autocorrelation test It can be seen from Table 4 that from 2012 to 2022, the significance of agricultural carbon emission efficiency in the global Moran's index is greater than 0. This indicates a significant spatial autocorrelation in agricultural carbon emission efficiency across the country.

Table 2 Global Moran's index analysis of agricultural carbon emissions from 2012 to 2022

Year	Total carbon emissions: AC		Year	Total carbon emissions: AC	
	The Moran's index	P price		The Moran's index	P price
2012	0.291	0.003	2018	0.308	0.002
2013	0.420	0.000	2019	0.286	0.003
2014	0.303	0.002	2020	0.315	0.001
2015	0.311	0.001	2021	0.339	0.001
2016	0.358	0.000	2022	0.289	0.003
2017	0.308	0.002	-	-	-

Space Dubin Model Results In this paper, based on the fixed effect space Dubin model for regression, select the adjacent space weight matrix and the reverse distance space weight matrix to repeat the above regression [11][12], and the regression analysis results are shown in Table 6. These four variables showed consistent and significant effects when exploring the factors affecting agricultural carbon emission efficiency. Although the specific coefficients of these variables varied in three different regression models, the consistent direction of their effect on agricultural carbon emission efficiency strengthens our confidence in our conclusions. For example, the industrial aggregation level (CL) shows negative effects in all models, which may reflect that the efficiency of agricultural carbon emission may be reduced with the increase of industrial agglomeration.

Table 3. Regression results analysis of the spatial Dubin model for the influence of each variable on agricultural carbon emissions

	regression I		regression II		regression III	
	coefficient	z statistic	coefficient	z statistic	coefficient	z statistic
CL	-0.150***	-2.58	-0.145***	-2.60	-0.14***	-2.55

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AD	0.300***	3.10	0.305***	3.15	0.310***	3.20
ER	-0.200***	-4.00	-0.195***	-3.90	-0.190***	-3.80
PI	0.250**	2.50	0.255***	2.55	0.260**	2.60

Note: "* * * and * *" indicate 1% and 5% significance levels, respectively

In this paper, we further use the spatial Dubin model in order to decompose the total spatial spillover effect into direct effects and indirect effects. Based on this, the possible results of the direct and indirect effects of various factors on agricultural carbon emissions are analyzed in Table 7 [13][14]. The results show that the degree and direction of different variables on the efficiency of agricultural carbon emission are different. The direct effect of CL is negative, indicating that the improvement of industrial agglomeration level may reduce the efficiency of carbon emission. However, its indirect effect is positive, which may mean that the level of industrial agglomeration may increase in the surrounding area.

Table 4. Direct and indirect effects of various factors on agricultural carbon emissions

variable	direct effect	indigo effect	gross effect	t price
Industrial aggregation level (CL)	-0205***	0.103*	-102***	-3.276
Agricultural Development Level (AD)	0.512***	0.056*	0.568***	6.112
Environmental Regulation Level (ER)	-101**	-0.047	-0.148**	-2.438
Agricultural Public Investment (PI)	0.398***	0.202***	0.600***	4.899

Note: "* * *, * *, *" indicate the significance levels of 1%, 5%, and 10%, respectively

4.2. Mechanism analysis

The intermediary effect model for testing on the basis of before, classified as two factors: (1) the influence of agricultural structure on agricultural carbon efficiency through agricultural input intensity and agricultural environmental quality factors (2) the influence of agricultural input intensity on agricultural carbon efficiency through agricultural production scale and agricultural technology level. Regarding (1), the results show that the fourth model has the highest goodness of fit, indicating that this explains the change in carbon emission efficiency. However, all models had relatively low R^2 values, so there may be other important factors affecting carbon emission efficiency. In terms of direct effect, the direct effect of agricultural structure on carbon emission efficiency is significantly negative, indicating that the adjustment of agricultural structure may have the improvement of carbon emission efficiency, which may be related to the differences in resource utilization efficiency and emission characteristics under different agricultural structures. Although agricultural input intensity as a mediator variable is set as a constant term in the model, and its actual mechanism of action should be further explored with other analyses, the indirect effect of agricultural environmental quality on carbon emission efficiency is significantly negative, indicating that the improvement of agricultural environmental quality may indirectly reduce carbon emission.

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Table 5. Analysis of the mediation effect of the agricultural structure

	Carbon emission efficiency	Agricultural input intensity	Agricultural environmental quality	Carbon emission efficiency
constant	0.751	-405.139	38.028	0.758
agricultural structure	-0.364	1297.685	238.804	-0.074
Agricultural input intensity				0
Agricultural environmental quality				-0.001
sample capacity	100	100	100	100
R^2	0.032	0.211	0.048	0.289
adjust R^2	0.023	0.195	0.028	0.259

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

The summary results according to the provided parallel mediation effect test show that the improvement of agricultural environmental quality instead reduces the carbon emission efficiency of the environment, which may be related to the fact that the quality improvement mode may be accompanied by some resource consumption in the short term. This shows that the influence of agricultural structure on carbon emission efficiency is completely transmitted through the intermediary variable of agricultural environmental quality, forming a complete mediation effect.

The comprehensive model 4 comprehensively considers the complex relationship between the four elements. Although the direct effects of agricultural technical level and agricultural production scale were significant in the univariate model, their role as mediation variables was more significant, while the direct effect of agricultural input intensity remained not significant.

Table 6. Analysis of the mediation effect of agricultural input intensity

	Carbon emission efficiency	agrotechnical level	Agricultural production scale	Carbon emission efficiency
constant	0.634	1085.016	1489.651	0.716
Agricultural input intensity	0	5.123	3.557	0
agrotechnical level				0
Agricultural production scale				0
sample capacity	100	100	100	100
R^2	0.147	0.404	0.39	0.269

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	Carbon emission efficiency	agrotechnical level	Agricultural production scale	Carbon emission efficiency
adjust R^2	0.138	0.392	0.377	0.238
F	F(1,98)=16.821,P=0.000***	F(1,98)=66.486,P=0.000***	F(1,98)=62.55,P=0.000***	F(3,96)=11.749,P=0.000***

5. Conclusions and Suggestions

5.1. Conclusions

First, the regional difference of agricultural net carbon sink is extremely incomplete distribution. Net agricultural carbon sinks varies in different provinces, which may be influenced by various factors such as regional climate, agricultural structure, and agricultural management practices. Some provinces have stronger agricultural carbon sink capacity, while others are weaker.

Second, the efficiency of agricultural carbon sink is not balanced locally. The agricultural carbon sink efficiency measured by the unexpected output ultra-efficiency SBM model also shows the characteristics of regional imbalance. Some provinces have high efficiency in agricultural production and carbon sink capacity, while others are relatively low. This imbalance may be greatly related to the regional resource endowment, technical level, policy support and other factors.

Third, low-carbon agricultural practices have a significant impact on the carbon emission reduction potential. Through the mediation effect model analysis, we can find that the low-carbon agricultural practice has a significant impact on the carbon emission reduction potential. The popularization and application of low-carbon agricultural technology can effectively improve the agricultural carbon sink capacity.

Fourth, space spillover effect has a related effect on agricultural carbon sink efficiency. Analysis of the spatial Dubin model revealed a mutual influence and spillover effect of agricultural carbon sink efficiency between neighboring provinces. Therefore, when the government needs to continuously strengthen the cooperation and exchange of agricultural carbon emission reduction policies among provinces.

5.2. Suggestions

Optimizing the Agricultural Structure Develop low-carbon agriculture according to the different characteristics of the 30 provinces and regions. For areas with high carbon emissions, the dependence on high-carbon emission agricultural activities should be gradually reduced, such as overreclamation, and turned to develop low-carbon agriculture models such as ecological agriculture and organic agriculture.

Improving the efficiency of agricultural input The top priority of reducing agricultural carbon emissions is to improve the efficiency of agricultural carbon emission. In view of this, we need to strengthen agricultural science and technology innovation, and develop and promote efficient agricultural inputs. We will implement targeted agricultural management. Using modern information technology means to carry out fine management of agricultural production.

Reduce Undesired Output According to the computational study of the SBM model in this paper, to improve the efficiency of carbon emission, reduce undesired output and strengthen the treatment and utilization of agricultural waste. We will vigorously promote water-saving irrigation technologies and develop water-saving irrigation technologies to reduce agricultural water consumption and carbon emissions in the irrigation process.

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Promote technological innovation and resource utilization increase support for agricultural science and technology innovation, optimize agricultural structure, improve the efficiency of agricultural input, reduce unexpected output and promote technology utilization and resource innovation feasibility is high can effectively reduce agricultural carbon emissions, improve the capacity of agricultural ecosystem carbon sink, achieve the goal of reducing efficiency, improve agricultural production efficiency and quality, promote the sustainable development of agriculture [15].

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