DOES AGRICULTURAL PRODUCTIVE SERVICE PROMOTE AGRO-ECOLOGICAL EFFICIENCY? Evidence From China

by

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Given the background of the rural population ageing, the reduced agricultural non-point source pollution and the decreased agricultural carbon emission, agricultural producer services, as an important bridge between small farmers and modern agriculture, are an important path to ensure food security and the green development of agriculture. Based on panel data of 31 provinces in China from 2003 to 2020, this paper uses Slack-based measure model with undesirable outputs (SBM-undesirable model)to calculate the agricultural ecological efficiency of 31 provinces. Furthermore, the two-stage least squares, the panel threshold model and the spatial Durbin model are used to empirically analyze the influence mechanism and the spatial spillover effect of agricultural productive services on agricultural ecological efficiency. The results show that agricultural producer services have a significant non-linear impact on agricultural ecological efficiency. Rural residents' income and per capita cultivated land area can adjust the relationship between them. The two main ways for agricultural productive services to improve agricultural ecological efficiency are as follows: reducing undesirable outputs such as pesticides, chemical fertilizers and plastic sheeting for agricultural use and improving agricultural production efficiency. In addition, agricultural producer services have a significant positive spatial spillover effect on agricultural ecological efficiency, and the indirect impact elasticity of spatial spillover is higher than the direct impact elasticity. Therefore, to achieve food security and promote the sustainable development of agriculture, it is necessary to vigorously develop agricultural productive services through multiparty cooperation.

Key words: *agricultural productive services, agro-ecological efficiency, food security, Agricultural sustainable development, agricultural carbon emissions, SBM-undesirable model, spatial durbin model*

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Introduction

Climate change has become an important factor restricting economic and social development. In the agricultural field, which is highly dependent on climate, and the climate change has intensified the sensitivity and vulnerability of agricultural production [1, 2]. Carbon emissions from agricultural production is an important part of GHG emission [3]. Reducing GHG emissions is crucial to ensuring food security and sustainable agricultural development. Furthermore, agricultural productive services not only alleviate the negative impact of rural labor population ageing and nonagricultural problems on agricultural production, but also encourage small farmers to adopt green and low-carbon production behavior and reduce agricultural pollution [4]. According to statistics, in the pilot area of agricultural producer services, the average yield of grain per acre increased by 10-20%, the average income of farmers per acre increased by 150-300 Yuan, and the use of chemical fertilizers and pesticides decreased by 10-25% on average. Remarkable results have been achieved in terms of agricultural cost savings, increasing efficiency, increasing farmer income and green development. Do agricultural producer services reduce agricultural carbon emissions and improve China agricultural ecological efficiency? Does it have a non-linear impact and spatial spillover effect on the improvement of agricultural ecological efficiency? Answering these questions will provide a new research perspective for promoting the green and sustainable development of agriculture in China, which has great theoretical and practical significance.

In recent years, research on agricultural producer services has attracted significant attention from academic and industrial communities. Scholars have affirmed the important role of agricultural producer services and have found that they are conducive to improving the efficiency of agricultural production and increasing farmers' income [5], significantly reducing agricultural production costs [6]. On the empirical aspect of the impact effect of agricultural producer services, scholars empirically pointed out that agricultural producer services can improve agricultural production efficiency and enhance agricultural competitiveness. They can also improve the technical efficiency of corn production, increase grain output, and increase farmers' income [7-9].

Through combing the relevant literature, it is found that although scholars have conducted much research on relevant issues and produced valuable research results, there is little involvement in the impact mechanism of agricultural producer services on improving agricultural ecological efficiency. Based on this, starting from the promotion mechanism, this paper uses the SBM undesirable model to calculate the agricultural ecological efficiency of 31 provinces in China from 2003 to 2020. The income level of rural residents and per capita cultivated land area are taken as threshold variables. A panel threshold regression model is used to analyze the adjustment of farmers' income levels and per capita cultivated land area. On the basis of further decomposing the input factors, the panel smooth transfer regression model is used to explore the non-linear impact mechanism of agricultural producer services on agricultural ecological efficiency. In addition, the spatial panel econometric model is used to explore its spatial spillover effect. The marginal contribution of this study is mainly reflected in the construction of the basic theoretical framework for agricultural producer services to improve agricultural ecological efficiency. It also analyzes its promotion role and the impact mechanism behind it. The constraints and spatial spillover effects behind the non-linear effects are further discussed. This study provides a new research perspective for ensuring the national food supply, implementing new development concepts and realizing high-quality sustainable development of agriculture.

Models, variables and methods

Research hypothesis

The economic objective of agricultural ecological efficiency is to minimize the input and unexpected output when the expected output is certain. When the expected output of agriculture is certain, once the input factors and unexpected output are reduced, it indicates that the agricultural ecological efficiency is improved, and the greater the reduction is, the greater the agricultural ecological efficiency will be improved [10, 11]. The mechanism of agricultural producer services to improve agricultural ecological efficiency can be analyzed from two aspects. Firstly, the development of agricultural producer services reduce the input of environmental factors and carbon emissions to improve agricultural ecological efficiency. Secondly, the efficiency of agricultural production in China improves the efficiency of agricultural ecology. In addition, the demand for agricultural productive services will be affected by the individual characteristics and factor endowments of farmers [12]. The scattered and sporadic distribution of traditional plots will affect the development of agricultural productive services. Therefore, under the assumption of a rational economic man, a farmer with a low income level (or with small-scale operations) will be more inclined to maintain the *status quo* for the introduction of new production factors from the perspective of risk aversion, which will inevitably affect their decision-making regarding production services [13] and will affect the role of agricultural producer services in improving agricultural ecological efficiency. Based on the above analysis, this paper proposes the following hypotheses.

Hypothesis 1: Agricultural producer services can significantly improve agricultural ecological efficiency, and their impact is non-linear, which is constrained and regulated by farmers' income level and per capita cultivated land area.

Hypothesis 2: Agricultural producer services can improve agricultural ecological efficiency by reducing the input of various environmental factors.

It is worth noting that producer services are characterized by strong spatial mobility, high integration and strong driving effects, which can affect agricultural production activities in the surrounding areas through spillover, demonstration, and imitation. However, there are certain differences in resource endowments and economic development conditions among different regions. Therefore, the impact of agricultural producer services on agricultural ecological efficiency may have regional differences and spatial spillovers. Therefore, the following *hypothesis 3* is proposed.

Hypothesis 3: Agricultural producer services have obvious regional differences in improving agricultural ecological efficiency, and the spatial spillover effect is significant.

Measurement of agricultural ecological efficiency

This paper combines the requirements and reality of agricultural ecological development based on relevant research and selects seven types of input indicators, one type of expected output and one type of unexpected output to construct the agricultural ecological efficiency evaluation index system. The input indicators are labor, land, chemical fertilizer, pesticide, plastic sheeting for agricultural use, agricultural machinery power, and irrigation. The expected output is represented by gross agricultural output value, and unexpected output is represented by carbon emissions. Based on agricultural carbon emissions combined with relevant research on unexpected agricultural output, this paper selects the six indicators for estimation, they are chemical fertilizer, pesticide, plastic sheeting for agricultural use, farm diesel fuel, agricultural irrigation, and agricultural cultivation. The emission coefficients of the above six types of emission sources are 0.896 kg/kg, 4.934 kg/kg, 5.180 kg/kg, 0.593 kg/kg, 20.476 kg/HA, and 312.6 kg/HA, respectively [14, 15]. In this paper, the SBM undesirable model [16, 17] is used to measure agricultural ecological efficiency.

Models and variables

This paper argues that the impact of agricultural producer services on agricultural ecological efficiency is non-linear, and there is obvious spatial spillover. Therefore, this paper constructs a multiple panel threshold regression model and a spatial econometric model to measure its impact. The multiple panel threshold regression model is set:

$$ECE_{it} = C + C_{11}PS_{it}(y_{it} \le \lambda_1) + C_{12}PS_{it}(\lambda_1 < y_{it} \le \lambda_2) + \ldots + C_{1n-1}PS_{it}(\lambda_{n-1} < y_{it} \le \lambda_n) +$$
$$+ C_{1n}PS_{it}(y_{it} > \lambda_n) + C_2FA_{it} + C_3GDP_{it} + C_4IND_{it} + C_5ET_{it} + C_6DS_{it} + \varepsilon_{it} \quad (1)$$

where *ECE* is the agricultural ecological efficiency, *PS* – the agricultural productive services, *y* – the threshold variable, and represents the per capita disposable income level (or per capita cultivated land area) of rural residents. The output value of agricultural producer services per mu (about 666 m^2) is used as a measure of the development level of agricultural producer services. The $\lambda_1, \lambda_2, \ldots, \lambda_{n-1}, \lambda_n$ – the threshold values in the corresponding threshold interval, $C_{11}, C_{12}, \ldots, C_{1n-1}, C_{1n}$ – the parameters to be estimated under different threshold intervals. The control variables selected in this paper mainly include the financial support for agriculture, *FA*, the economic development level, *GDP*, the industrialization level, *IND*, the education level, *ET*, and the disaster stricken level, *DS*.

Before spatial correlation analysis and spatial model verification, it is necessary to select the appropriate spatial weight matrix. This paper selects the most commonly used spatial geographical weight matrix, w_1, for analysis.

$$W_1 = \begin{cases} \dfrac{1}{d_{ij}} & i \ne j \\ 0 & i = j \end{cases} \quad i, j = 1, 2, \ldots, \quad n \quad (2)$$

where d_{ij} is the spherical distance between the capital cities of two provinces and it is standardized. Considering the spatial correlation between independent variables and dependent variables, this paper selects the spatial panel Durbin model to analyze the impact of agricultural productive services on agricultural ecological efficiency. The model is:

$$ECE_{it} = \alpha + \beta WECE_{it} + \delta WX_{it} + \beta_1 PS_{it} + \beta_2 GDP_{it} + \beta_3 FA_{it} +$$
$$+ \beta_4 INT_{it} + \beta_5 ET_{it} + \beta_6 DS_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (3)$$

where *W* is the spatial weight matrix of independent variable and dependent variable, *X* – the set of all explanatory variables and control variables, and the meaning of variables is the same as above, and ε – a random error term satisfying independent and identically distributed.

Considering the reality of agricultural development, the availability of data and the implementation of the new national economic industry classification in 2003, some modifications and adjustments involved in agricultural producer services are made, and the sample selected in this paper is 31 provinces, municipalities directly under the central government, and autonomous regions in China from 2003 to 2020. The data in this paper come from the China

Statistical Yearbook, the China Rural Statistical Yearbook, the China Agricultural Machinery Industry Yearbook, the provincial and municipal statistical yearbooks and the provincial and municipal rural statistical yearbooks. The descriptive statistical analysis of each variable is shown in tab. 1. To eliminate the influence of heteroscedasticity, all data are processed with logarithm.

Table 1. Descriptive analysis of variables

Variable	Variable description	Mean	Standard deviation
log(*ECE*)	According to the index system, the SBM model with unexpected output is used for calculation	3.3473	0.5524
log(*income*)	Expressed by per capita income of rural residents	8.8158	0.6737
log(*parea*)	Represented by per capita cultivated land area	2.0639	0.4802
log(*PS*)	Expressed by the output value of agricultural productive services per mu	7.3373	0.8709
log(*FA*)	Measurement of the proportion of agricultural and forestry water affairs expenditure in the general budget expenditure of local finance	2.2527	0.3994
log(*GDP*)	Measured by per capita GDP	10.3140	0.7623
log(*IND*)	Measuring the proportion of GDP in secondary industry	3.5711	0.3844
log(*ET*)	Measured by the average years of education of farmers and residents	1.9928	0.1366
log(*DS*)	The ratio of affected area of crops to total disaster-affected area	2.7638	0.8349

Empirical results and analysis

Panel model estimation results

On the basis of the F-test, LM-test, and Hausman-test, this paper selects the fixed effect model and takes the results of the random effect model as a reference for the stability test. It further considers the endogenous problem, takes the development level of agricultural producer services lagging behind Phases I, II, and III as the tool variables, and uses the two-stage least squares (2SLS) for its estimations. The final estimation results are shown in tab. 2.

Table 2 shows that the impact of the development of agricultural producer services on agricultural ecological efficiency is positive, which passes the test at the 1% significance level. The 2SLS estimation results show that the impact elasticity of agricultural producer services on China agricultural ecological efficiency is 0.1416, and the development of agricultural producer services can significantly improve China agricultural ecological efficiency. When endogenous issues are not considered, the role of agricultural producer services in improving agricultural ecological efficiency will be increased. From the control variables, the level of economic development, the level of financial support for agriculture and the level of education all have a positive impact on agricultural ecological efficiency, while the impact of industrialization and agricultural disaster area is negative.

Table 2. Panel regression estimation results

Variable	Fixed effect model	Random effect model	Two-stage least squares (2SLS)
Intercept	–	–1.795 9*** (–5.188 6)	–1.705 0*** (–4.980)
log(*PS*)	0.184 2*** (6.972 3)	0.175 1*** (7.132 8)	0.141 6*** (5.976)
log(*GDP*)	0.308 3*** (9.954 3))	0.321 2*** (11.188 5)	0.336 9*** (5.976)
log(*FA*)	0.081 4 (1.555 3)	0.113 9** (2.631 1)	0.133 0*** (3.367)
log(*IND*)	–0.536 7*** (–8.584 0)	–0.486 5*** (–8.930 9)	–0.283 1*** (–6.740)
log(*ET*)	1.314 7*** (4.747 8)	1.102 4*** (5.341 0)	0.779 5*** (5.429)
log(*DS*)	–0.055 1*** (–3.508 2)	–0.061 8** (–4.014 0)	-0.107 6*** (–5.597)
Adjusted R^2	0.829 5	0.832 2	0.695 2

Note: *, **, *** indicate, respectively, that they are significant at the 10%, 5%, and 1% levels, and the values in brackets are *p* values or *t* statistics.

Result analysis of the panel threshold regression model

This paper uses the bootstrap method for testing. The test results show that when the per capita disposable income and per capita cultivated land variables are used as threshold variables, the first, second, and third thresholds all pass the significance test below the 5% significance level. Therefore, the triple threshold model is selected for analysis. The model estimation results are shown in tab. 3.

Table 3. Estimation results of the panel threshold regression model

Variable	Threshold value (Income level)	Model coefficient	Threshold value (cultivated area)	Model coefficient
log(*PS*)	< 527 6.69	0.124 0*** (3.42)	<7.147 6	0.1532*** (3.25)
log(*PS*)	(5276.69, 6990.3)	0.141 6*** (3.60)	(7.1475, 9.0784)	0.174 9*** (3.60)
log(*PS*)	(6990.3, 14512.2)	0.159 0*** (3.78)	(9.0784,10.5127)	0.187 2*** (3.53)
log(*PS*)	> 14512.2	0.181 6*** (4.12)	>10.512 7	0.216 5*** (3.98)
log(*GDP*)	–	0.221 9 ** (2.09)	–	0.221 9 ** (2.09)
log(*FA*)	–	0.122 4** (1.93)	–	0.122 4** (1.93)
log(*IND*)	–	–0.330 9** (2.61)	–	–0.330 9** (2.61)
log(*ET*)	–	1.086 4** (2.76)	–	1.086 4** (2.76)
log(*DS*)	–	–0.037 8*** (–2.73)	–	–0.037 8*** (–2.73)

Table 3 shows that the corresponding threshold values of the triple threshold model with per capita disposable income as the threshold variable are 5276.69, 6990.30, and 14512.2, respectively, and the elasticity coefficients of the impact of agricultural producer services on agricultural ecological efficiency are 0.1240, 0.1416, 0.1590, and 0.1816, respectively, which all pass the test below the 1% significance level. The results show that with the increase in the per capita disposable income of rural residents, the impact of the development of agricultural producer services on China agricultural ecological efficiency has gradually increased. When the per capita cultivated land area is taken as the threshold variable, with the increase in per capita cultivated land area, the impact elasticity coefficients are 0.1532, 0.1749, 0.1872, and 0.2165, respectively, which all pass the significance test. With the expansion of arable land per capita, the impact of agricultural productive services on agricultural ecological efficiency gradually increases. This shows that the impact of agricultural services on agricultural ecological efficiency is constrained and regulated by farmers' income level and per capita cultivated land area, and that its impact is non-linear. With the increase in farmers' income level and per capita cultivated land area, its impact elasticity gradually increases; thus, *Hypothesis 1* has been verified.

Robustness test

This paper selects the panel smooth transfer regression model (PSTR) model for the robustness test and takes the per capita disposable income of rural residents and per capita cultivated land area as conversion variables. The results are shown in tab. 4. The results are basically consistent with the panel threshold regression estimation results, indicating that the empirical results of this paper are relatively stable.

Table 4. Robustness test results based on the PSTR model

Model	log(*PS*)		log(*GDP*)	log(*FA*)	log(*IND*)	log(*ET*)	log(*DS*)
	Linear parts	Non-linear part					
1	0.0233^{**}	0.1683^{***}	0.1327^{**}	0.0011^{*}	$–0.2579^{**}$	0.5924^{***}	$–0.0186^{**}$
2	0.1573^{***}	0.0897^{***}	0.2515^{***}	0.0763^{*}	$–0.5399^{**}$	1.4355^{*}	$–0.0387^{***}$

Note: The conversion functions of Model 1 and Model 2 are rural per capita disposable income and per capita arable land, respectively.

Influencing mechanism analysis

To further verify the non-linear impact mechanism of agricultural producer services on the input factors of agricultural ecological efficiency, this paper first decomposes the input factors and then constructs a panel smooth transfer model between the input factors and the development level of agricultural producer services. The test results show that there are non-linear effects. The results of the PSTR are shown in tab. 5. The dependent variables of Models 1-7 are the agricultural labor input, the land input, the chemical fertilizer input, the pesticide input, the agricultural film input, the mechanical power input and the irrigation input, respectively.

Table 5 shows that agricultural productive services will significantly reduce the agricultural labor input, the fertilizer input, the pesticide input and the agricultural film input, and increase the agricultural machinery power input and the irrigation input. Among them, the fertilizer input, the pesticide input and the agricultural film input are the main pollution sources of the agricultural non-point source pollution. The analysis shows that agricultural producer services will effectively reduce the input of various environmental factors, thus reducing unexpected output and further improving agricultural ecological efficiency. Thus, *Hypothesis 2* is verified. At the same time, agricultural productive services will reduce the labor input and increase the mechanical power input and the irrigation input. When the output is certain, the increase in the agricultural mechanization input and decrease the labor input will effectively improve the agricultural production efficiency and then improve the agricultural ecological efficiency, which is basically consistent with the previous theoretical analysis.

Table 5. Non-linear impact mechanism

Model	Agricultural productive services	
	Linear part	Non-linear part
Model 1	–0.0534** (0.0248)	–0.0015*** (0.0008)
Model 2	–0.0532*** (0.0249)	0.0120*** (0.0058)
Model 3	–0.0116*** (0.0288)	–0.0097*** (0.0030)
Model 4	–0.7498*** (0.6843)	–1.2587*** (1.3264)
Model 5	–0.0256**(0.0950)	–0.0189***(0.0084)
Model 6	0.1287*(0.0458)	0.0064*** (0.0025)
Model 7	0.026** (0.0278)	0.0069** (0.0051)

Analysis of the spatial spillover effect

Geographical economists believe that because the adjacent space is very similar in economic characteristics, resource endowments and other aspects, local agricultural ecological efficiency will be affected not only by local agricultural productive services, but also by those in the adjacent areas. Through the Moran index test, it is found that the Moran's I index of agricultural productive services fluctuated approximately 0.15 from 2003 to 2020 and pass the test at the 5% significance level. Therefore, it is necessary to consider the spatial effect. The test shows that the spatial panel Durbin model with fixed effects should be selected. The results of the Wald and LR tests show that the spatial panel Dobbin model cannot be degenerated into a spatial lag model and a spatial error model. For comparison and the stability test, tab. 6 shows the comparison results of different models.

Table 6. Spatial effect estimation results

Variable	Spatial error model	Spatial lag model	Spatial Durbin model	Spatial Durbin error model
log(*PS*)	0.1919 *** (7.54)	0.1078*** (4.49)	0.0899*** (3.55)	0.0766 *** (3.06)
log(*GDP*)	0.2962 *** (10.22)	0.1625*** (5.46)	0.1297*** (3.97)	0.1159*** (3.68)
log(*FA*)	0.0730 (1.36)	–0.0529 (–1.16)	–0.1422** (–2.47)	–0.1571*** (–2.68)
log(*IND*)	–0.5584*** (–8.64)	–0.3746*** (–6.53)	–0.3865*** (–3.35)	–0.3979*** (–5.89)
log(*ET*)	1.3031*** (4.79)	0.6801*** (2.79)	0.2979 (1.10)	0.2180 (0.43)
log(*DS*)	–0.0603*** (–3.99)	–0.0265 (–1.68)	–0.0228 (–1.38)	–0.0265(–1.68)
W*log(*PS*)	–	–	0.0597* (1.72)	0.0114* (1.82)
W*log(*GDP*)	–	–	0.0070 (0.27)	0.0223 (–1.11)
W*log(*FA*)	–	–	0.0548 (0.58)	0.0899 (1.15)
W*log(*IND*)	–	–	0.0544 (0.45)	0.2205** (2.24)
W*log(*ET*)	–	–	1.3639** (2.48)	0.5937 (1.26)
W*log(*DS*)	–	–	–0.2246** (–2.60)	–0.2358*** (–2.73)
λ	–	0.5316*** (12.35)	0.4339*** (6.98)	0.6749*** (10.86)
ρ	0.3824*** (25.62)	–	–	–0.5227*** (–3.70)

According to tab. 6, it is considered that the estimation result of the panel data space Durbin model is robust. It is found that the impact of agricultural producer services on agricultural ecological efficiency is significantly positive, which has passed the test at the 1% significance level. The impact elasticity of w*log (PS) is positive, indicating that agricultural producer services also have a significant positive impact on the surrounding areas. Thus, *Hypothesis 3* has been verified. According to the effect decomposition calculated by the partial differential equation, the direct impact elasticity of agricultural producer services is 0.1251, the indirect impact elasticity is 0.1879, and the total effect is 0.3130. The contribution of the spatial spillover effect on the development of agricultural producer services is greater than the direct effect. Therefore, the spatial spillover effect of agricultural producer services on agricultural ecological efficiency cannot be ignored.

Conclusion and discussion

The empirical results show that agricultural producer services can improve China agricultural ecological efficiency, and its impact is non-linear, which will be affected by the per capita income level and per capita cultivated land area. When the threshold is exceeded, the impact of agricultural productive services on the agricultural ecological efficiency increases. In addition, the impact of agricultural producer services on the agricultural ecological efficiency has an obvious spatial spillover. Therefore, when analyzing the impact of agricultural producer services on the agricultural ecological efficiency, we cannot ignore the relevant constraints, impact mechanisms, and spatial spillovers. This paper finds that the development of agricultural producer services effectively reduces the input of various environmental factors, which are the main sources of agricultural non-point source pollution and agricultural carbon emissions. Therefore, vigorously developing agricultural productive services is an important way to reduce agricultural carbon emissions and achieve sustainable agricultural development. However, there are still some shortcomings in the research. On the one hand, if the existing provincial panel data can be replaced by micro survey data, the model results may be more representative. On the other hand, for the measurement of agricultural ecological efficiency, the output only considers total agricultural output value and agricultural carbon emissions but does not consider the grain output, nitrogen pollution, phosphorus pollution and so on. In addition, when measuring the spatial spillover effect, only a weight matrix of geographical distance is considered, while economic distance is not considered. These aspects can be improved in subsequent studies.

To be summarized, our findings pave the way toward an expanded perception of agricultural productive services, and has opened a new chapter of the agro-ecological efficiency.

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