Pol. J. Environ. Stud. Vol. 32, No. 6 (2023), 5527-5541
DOI: *10.15244/pjoes/169897* ONLINE PUBLICATION DATE: 2023-09-25

Original Research

Nonlinear Effect of Farmland Management Scale Expansion on Agricultural Eco-Efficiency: A Moderating Effect of Service Outsourcing

Changming Cheng[1, 2], Jieqiong Li[3], Mengyuan Sun[1], Qingwei Cao[4], Qiang Gao[1]*

[1]College of Economics and Management, Nanjing Forestry University, Nanjing 210037, China
[2]School of Economics and Management, Chuzhou University, Chuzhou 239000, China
[3]Science and Technology Department, Nanjing Forestry University, Nanjing 210037, China
[4]Real Estate Registration Center, Natural Resources and Planning Bureau of Yantai Economic and Technological Development Zone, Yantai 264006, China

Received: 5 June 2023
Accepted: 22 July 2023

Abstract

Agricultural eco-efficiency is a crucial indicator for measuring the green and sustainable development of agriculture. This study utilizes provincial panel data from 2006 to 2019 to measure agricultural eco-efficiency while integrating carbon emissions and carbon sinks. A two-way fixed effect model and a nonlinear quadratic term model are utilized to investigate whether expanding farmland management scale contributes to enhancing agricultural eco-efficiency. The research results indicate that agricultural eco-efficiency is at a moderate level and exhibits a positive trend with an average annual growth rate of 1.28%. The relationship between farmland management scale and agricultural eco-efficiency is characterized by an inverted U-shaped nonlinear association. Appropriate management scale is essential for promoting green development of agriculture and is validated even after conducting endogenous and robustness tests. The research identified a significant moderating effect of service outsourcing, where a higher degree of service outsourcing results in a flatter inverted U-shaped curve mentioned above. Moreover, the non-linear relationship between the scale of agricultural land and agricultural eco-efficiency has become more significant after the reform of "separation of the three rights" and in the east and central regions. Finally, based on the above conclusions, the paper provides specific recommendations for improving agricultural eco-efficiency.

Keywords: farmland management scale, agricultural eco-efficiency, service outsourcing, carbon emissions, carbon sink

*e-mail: gaoqiang@njfu.edu.cn

Introduction

In recent years, since the release of, China's agricultural development has made significant progress owing to the implementation various policies and reforms [1-3]. However, China still faces practical challenges such as "more people and less land" as well as land fragmentation. Historically, agricultural growth in China has relied heavily on the excessive use of chemicals [4, 5], resulting in problems related to over-cultivated of land and inadequate utilization of waste resources. Unfortunately, these issues have persisted, further exacerbating challenges to the ecological environment of agricultural [6, 7]. Since the 18th CPC National Congress, the CPC Central Committee and the State Council have highlighted the importance of the green development of agriculture. In order to deal with agricultural non-point source pollution, declining cultivated land quality, over-management, ecological degradation and other issues, the state has successively issued a number of policies and regulations, placing agricultural green development at the forefront of future development and construction, with gradual increases in policy innovation and system supply. In recent years, China's No.1 Central Document has made relevant arrangements for the green development of agriculture. Since 2016, the document has proposed to enable the green development of agriculture by strengthening pollution prevention, reducing resource use and restoring impacted ecological systems. The Law of the People's Republic of China on Promoting Rural Revitalization, which came into effect in June 2021, put forward clear requirements and development goals for government at all levels to carry out agricultural non-point source pollution prevention and control from the legal level. In 2022, the report of the 20th National Congress of the Communist Party of China clearly proposed to accelerate the green transformation of development methods, and continued to promote green development, circular development, and low-carbon development.

Specifically, there are two main ways to promote green agricultural development. First, change the management mode, which will improve the efficiency of resource utilization by carrying out efficient and intensive management. Second, strengthen the management of inputs, so that we can better understand the relationship between prevention and control by adopt advanced technologies. Land is an input factor for agricultural management and deeply affects the business behavior of farmers. The development of moderate scale agricultural management is the direction of modern agriculture. China's No.1 Central Document in 2023 pointed out that it is necessary to guide the orderly transfer of land management rights and develop moderate scale agricultural operations. According to data from the agricultural and rural sectors, by the end of 2019, the circulation area of household contracted farmland in China is 555 million acres, accounting for 35.9% of the total household contracted farmland area, with the majority of areas transferred to farmers (312 million mu), followed by cooperatives (126 million mu). On the other hand, the scale of farmland management in China has increased from 0.476 hectares per person in 2006 to 0.890 hectares per person in 2021, an increase of 1.870 times. Agricultural eco-efficiency is an important indicator for measuring the level of green development in agriculture.

There are great differences in production efficiency among different farmland management scales, and their influences on farmers' green production decisions and behaviors are also different. Agricultural eco-efficiency is an important index to measure the level of agricultural green development [8, 9]. Then, will the expansion of farmland management scale inevitably improve agricultural eco-efficiency? Some scholars believe that, with the expansion of business scale, production factors can be fully utilized, scale effect can be better utilized, and it has a positive impact on agricultural environment [10, 11]. At the same time, the expansion of farmland management scale is conducive to the realization of clean agricultural production, and can increase the recycling of waste and reduce the use of agricultural materials [12]. For example, Wu et al. (2018) pointed out that for every 1% increase in average household planting area, the application amount of chemical fertilizer and pesticide per hectare decreased by 0.3% and 0.5% respectively, and the application amount of chemical fertilizer per unit area decreased with the increase of planting area management scale [13]. However, it has also been pointed out that due to the influence of capital-driven and free resources, large-scale agricultural materials are often over-invested in the pursuit of output, resulting in an increase in agricultural non-point source pollution [14]. At the macro level, once the land management right is transferred, the pressure on agricultural ecosystem will increase due to various factors such as mechanization substitution and planting structure adjustment [15].

The aforementioned studies hold significant academic value in assessing the multifaceted effects resulting from the magnitude of agricultural activities. Furthermore, they offer valuable insights and serve as a solid foundation for the analysis of the impacts of relational agricultural operations and agroecological efficiency in this paper. However, it is crucial to acknowledge that the existing literature has not yet reached a consensus on this matter. This lack of consensus can be attributed to substantial regional disparities in resource allocation, variations in human-land interactions, and a limited focus on linear perspectives. It is worth noting that the relationship between farm operation scale and agricultural eco-efficiency may not be a simple linear relationship, that is, positive or negative impacts as mentioned above [16]. From an economic perspective, due to the diminishing marginal returns and internal uneconomic factors, in a certain range, the scale of farmland management may have a positive correlation with the promotion of agricultural eco-efficiency. However, after a certain range, the expansion of cultivated land management scale cannot continuously improve agricultural ecological efficiency, and even inhibit the improvement of agricultural ecological efficiency because it stabilizes agricultural eco-efficiency at a certain level. On the other hand, due to the comparative advantage of service scale and the strong support of the Chinese government, farmers will choose to outsource the agricultural production process in order to realize service scale operation. In view of this, this paper further brings service outsourcing into the research framework, and investigates the nonlinear relationship between farmland management scale and agricultural eco-efficiency, trying to reveal the regulatory role of service outsourcing. This corresponds to the current actual situation, and the findings of the study can help guide the policies related to land transfer.

Based on this, this paper explores the nonlinear relationship between the expansion of farmland management scale and agricultural eco-efficiency, and further argues for the moderating role of service outsourcing in it. This study's contributions are in the following three aspects: First, there are still some imperfections in the measurement of agricultural eco-efficiency in the existing research, which are mainly reflected in the fact that agricultural carbon sink has not been included in the model, and the measurement index system of agricultural carbon emissions needs to be improved. This paper presents a more accurate measurement of agricultural eco-efficiency by integrating agricultural carbon emissions and agricultural carbon sink, which sets the groundwork for exploring the nexus of farmland operation scale with agricultural economy and environment. Second, this study breaks through the hypothesis of linear relationship between farmland management scale expansion and agricultural eco-efficiency in previous literature, and examines the nonlinear relationship by incorporating the quadratic term of farmland management scale into the research framework. This approach better characterizes the mechanism of the impact of farmland management scale expansion, and expands the research literature on the mechanism of the relationship between farmland management scale expansion and agricultural eco-efficiency. Finally, this paper introduces a service outsourcing perspective and analyzes its regulatory role in the nonlinear relationship between farmland management scale expansion and agricultural eco-efficiency. This broader examination of the relationship between land scale and service scale in agricultural eco-efficiency provides a basis for relevant policy formulation. This issue holds theoretical and practical significance in promoting sustainable agricultural development in the context of land transfer promotion.

The rest of the study is arranged as follows. Section 2 presents literature review and the research hypothesis; section 3 proposes the data and methods used in this paper; section 4 is an empirical analysis; and section 5 discusses the conclusions and policy implications.

Literature Review and Research Hypothesis

Measurement of Agricultural Eco-Efficiency

Eco-efficiency was initially defined as the ratio of added value of economic activities to environmental load, and its core idea is to get the maximum economic output with the minimum resource consumption and pollution emission [17]. At present, the idea of eco-efficiency is widely used at the regional, industrial and individual levels [18-20]. Agriculture has the dual attributes of carbon emission and carbon sink. Under the goal of "carbon neutrality and carbon peaking", it is the general trend to reduce agricultural carbon emission and increase agricultural economy and carbon sink output. More and more researchers pay attention to agricultural ecological efficiency, and get as much expected agricultural output as possible by minimizing resource consumption and environmental pollution as possible, thus realizing the coordination of economic benefits and environmental benefits [8].

There are more studies on measurement of agricultural efficiency, and the methods mainly include parametric stochastic frontier analysis (SFA) and nonparametric data envelopment analysis (DEA), but these methods ignore the resource and environmental constraints, and it is difficult to objectively reflect the true performance level of agricultural development, and only by incorporating resource and environmental variables into the evaluation model can the true effectiveness of agricultural green development be examined. In the model construction, the treatment of agricultural pollution elements is an important part. There are two main ideas in existing studies: one is as an input and the other one is as a non-desired output. From the perspective of production, the latter is more reasonable and more widely used. While the SFA model can only use one output and it is difficult to take non-desired outputs into account, the non-radial, non-angle SBM-DEA model has the ability to deal with non-desired outputs and is widely used in agricultural eco-efficiency measurement [3]. For example, Chen et al. (2021) considers carbon emissions and agricultural surface pollution as non-desired outputs and explores the green total factor productivity of agriculture in 30 Chinese provinces [21]. Most studies chose agricultural carbon emissions as a poor output and applied the SBM model to comprehensively measure environmental efficiency, and the results generally reflected that the current agricultural green production efficiency is not high and there are obvious regional differences, but the general trend shows an increase. However, under the goal of carbon peaking and carbon neutrality, most studies only consider the undesired output of carbon emissions and ignore the carbon sink in crop growth.

Agriculture has the dual attributes of carbon sink and carbon source, and China's agriculture exhibits the outstanding characteristics of net carbon sink [22, 23]. Therefore, agricultural carbon sinks and agricultural carbon emissions need to be included in the same framework in order to measure agricultural eco-efficiency more scientifically.

Relationship Between Farmland Management Scale and Agricultural Eco-Efficiency

The expansion of farmland management scale has the potential to influence agricultural eco-efficiency in several ways. First, the expansion of farmland management scale can improve the previous fragmented and scattered land management model by making the land contiguous [24, 25]. This in turn can help resolve the issues associated with land fragmentation, by dividing land" according to people, contracted by households, and matching fat and thin", which will enable economic scaling, and thus help improve the output of farmland [26, 27]. Secondly, larger-scale land management leads to a significant reduction in chemical fertilizer usage [28], thereby contributing to the mitigation of agricultural carbon emissions [29], and improve the efficiency of environmentally friendly agricultural practices. This is partly due to the fact that certain technologies used as alternatives to chemical fertilizers can only be applied on a larger scale area [30]. Furthermore, the adoption of advanced agricultural technologies necessitates a certain level of fixed capital investment, and the cost of this investment can be spread out as the land area increases. Research also indicates that scale management can serve as a means of resource integration, as it encourages the optimal utilization of agricultural machinery and irrigation facilities. This not only enhances resource efficiency but also improves the quality of cultivated land [31]. Third, under market and government influence, land transfer from business households to efficient business households becomes more feasible [32]. This incentivizes farmers to professionalize their operations, allowing those with comparative advantages to acquire more land and specialize their labor accordingly [33]. These new agricultural business entities often have high technical literacy and environmental awareness, and tend to adopt agricultural green technology and advanced management methods to reduce the application of chemical fertilizers and pesticides and improve the level of agricultural mechanization, thus improving agricultural business performance [34, 35]. In addition, the expansion of farmland management can realize the rational distribution of land among different crops by optimizing the industrial structure, thus improving agricultural eco-efficiency.

Research has indicated that expanding the scale of arable land operation can enhance the agroecological environment, but it may also have adverse environmental impacts. It should be noted that farmers may unintentionally alter the business structures or mismanage pollutants, which can lead to an increase in agricultural non-point source pollution and the diseconomy of scale [36, 37]. Scholars suggest that the relationship between farmland management scale and agricultural eco-efficiency is not strictly linear, but demonstrates an inverted U-shaped function that increases initially and then subsequently decreases [16]. Zhao et al. (2021) have further confirmed that the relationship between management scale and fertilizer application intensity is not purely linear, but exhibits a positive "U-shaped" relationship that decreases initially and afterward increases [38]. In summary, this paper argues that there is a nonlinear relationship between farmland management scale and agricultural eco-efficiency. Specifically, when the positive effect of farmland operation scale expansion is stronger than the negative effect, the positive effect brought by scale effect and profit maximization claim is greater, and farmland operation scale expansion may promote the improvement of agricultural eco-efficiency. However, under the influence of the law of diminishing marginal returns, when the scale of farmland operation expands to a certain extent, the marginal returns of agricultural production start to diminish, and operators may increase chemical inputs to hedge risks, thus inhibiting the improvement of agricultural eco-efficiency. As a result, the following research hypothesis is proposed.

Hypothesis 1 (H1). There is an inverted U-shaped relationship between the scale of farmland management and agricultural eco-efficiency.

The Moderating Effect of Service Outsourcing

Existing studies show that agricultural scale operation has two main meanings: one is the scale of farmland and the other is the scale of services. With the accelerated urbanization in China and the continuous transfer of rural labor to cities and non-agricultural industries, outsourcing of services has become increasingly common, becoming an effective form of solving the fragmentation of farmland and realizing large-scale operation.

The impact of service outsourcing on agricultural eco-efficiency can be mainly viewed reflected two aspects. Firstly, from the supplier's perspective, the establishment of agricultural service organizations is advantageous achieving lean management, which in turn leads to reduced agricultural material inputs and improved production efficiency. Micro-empirical studies have demonstrated that agricultural social services can also positively influence farmers' production and management behaviors. For instance, these services can encourage farmers to reduce their use of fertilizers and pesticides, adopt environmentally friendly production techniques, and increase their willingness to engage in sustainable agricultural practices [39, 40], thus improving agricultural eco-efficiency. Secondly, from the demanders' perspective, the advantages of service outsourcing can be analyzed through the lens of the theory of division of labor economy. This approach effectively alleviates the labor and technological constraints faced by farmers during the agricultural production and operation process. Moreover, it compensates for the efficiency loss associated with small-scale operations, particularly in the context of labor outflow and inadequate resource provision [41].

Service outsourcing has a positive impact on agricultural eco-efficiency and plays a moderating role in the inverted U-shaped relationship between the expansion of farmland operation scale and agricultural eco-efficiency. Specifically, when the scale of farmland operation is small, the degree of fragmentation and decentralization of farmland is high. Although service outsourcing exerts the scale effect to a certain extent, it will weaken the positive effect of farmland operation scale expansion on agricultural eco-efficiency because the scale of outsourcing market is underdeveloped and there are speculative behaviors of service organizations, instead of promoting agricultural reduction [42]. When the scale of farmland operation is higher, on the one hand, the demand for outsourcing services is greater and the market is more competitive, forcing service outsourcing organizations to provide better quality services; on the other hand, the expansion of farmland operation scale brings greater scale effect, and the human, capital and technological advantages of service outsourcing can be better utilized. As a result, the following research hypothesis is proposed.

Hypothesis 2 (H2): The regulation of service outsourcing flattens the inverted U-shaped curve even more.

Research Methods and Data

Econometric Model

Referring to previous studies, the panel data were tested by Hausman test, and the results rejected the original hypothesis, so the fixed effect model was adopted. Previous studies have shown that there is a nonlinear relationship between farmland management scale and agricultural eco-efficiency. Since the impact of farmland management scale on agricultural eco-efficiency is likely to be nonlinear, so this paper adds a quadratic term of farmland management scale into the model to verify whether there is a nonlinear relationship between farmland management scale on agricultural eco-efficiency. The econometric model is as follows:

$$Aee_{it} = \beta_0 + \beta_1 Lnscale_{it} + \beta_2 Lnscale^2{}_{it} + \sum_{j=1}^{n} \beta_{j+2} Controls_{it} + \lambda_i + \mu_t + \varepsilon_{it} \tag{1}$$

In the formula, t and i represent time and the province, Aee_{it} represents agricultural eco-efficiency, $Lnscale_{it}$ and $Lnscale_{it}^2$ represent farmland management scale and the quadratic term of farmland management scale, $Controls_{it}$ represents a series of control variables, λ and μ_t represent regional fixed effect and time fixed effect, ε_{it} is the random perturbation term.

In order to test whether service outsourcing can regulate the scale of farmland management and agricultural eco-efficiency, this study introduced the primary and secondary terms of service outsourcing and farmland management scale into the econometric model as follows:

$$\begin{aligned} Aee_{it} &= \beta_0 + \beta_1 Lnscale_{it} + \beta_2 Lnscale^2{}_{it} \\ &+ \beta_3 Services + \beta_4 Services \times Lnscale_{it} \\ &+ \beta_5 Services \times Lnscale_{it}{}^2 + \sum_{j=1}^{n} \beta_{j+5} Controls_{it} \\ &+ \lambda_i + \mu_t + \varepsilon_{it} \end{aligned} \tag{2}$$

Variable Selection

Explained Variable

In order to comprehensively measure the agricultural eco-efficiency, this paper constructs the following indicator system from the perspective of input and output. In the process of agricultural production, the expected outputs (such as economic benefits and agricultural carbon sequestration) are always accompanied by some bad outputs, such as agricultural carbon emissions [43, 44]. Under the background of "carbon peaking and carbon neutralization", it is necessary not only to achieve high efficiency of agricultural production, but also to promote green and low-carbon development of agriculture [8]. Therefore, referring to the practice of scholars, this paper treats agricultural carbon emissions and agricultural carbon sinks as non-desired and desired outputs, respectively, and constructs a model including non-radial and non-angular Super-SBM to measure agricultural eco-efficiency [3, 23, 45]. The specific model is as follows:

$$\rho = \min \frac{\frac{1}{m}\sum_{i=1}^{m} \frac{\bar{x}}{x_{ik}}}{\frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1} \frac{\bar{y}^g}{y_{rk}^g} + \sum_{t=1}^{s_2} \frac{\bar{y}^b}{y_{tk}^b}\right)} \tag{3}$$

$$s.t.\begin{cases} \bar{x} \geq \sum_{j=1, j\neq k}^{n} \lambda_j x_{ij}, \bar{y}^g \leq \sum_{j=1, j\neq k}^{n} \lambda_j y_{rj}^g, \bar{y}^b \geq \sum_{j=1, j\neq k}^{n} \lambda_j y_{tj}^b \\ \bar{x} \geq x_k^{it}, \bar{y}^{g} \leq y_k^{g}, \bar{y}^b \geq y_k^b, \lambda_j \geq 0 \\ i = 1, 2, \cdots, m; j = 1, 2, \cdots, n \\ r = 1, 2, \cdots, s_1, t = 1, 2, \cdots, s_2 \end{cases} \tag{4}$$

Where ρ is the value of agricultural eco-efficiency; x, y^g and y^b represent the matrix corresponding to input, expected output and unexpected output respectively; When $\rho \geq 1$, the agricultural eco-efficiency is effective; when $\rho < 1$, the agricultural eco-efficiency does not reach the effective state, and the input or output is redundant or insufficient.

Considering that agriculture in a broad sense includes planting and crop farming, forestry, animal husbandry, fish farming and sideline activities, there are great differences among the different sub-industries. The term of agriculture is limited to the category of the plantation industry for the purposes of this paper. The evaluation index system of agricultural eco-efficiency was constructed according to relevant research [3, 44, 46]. The input index in this study encompasses three dimensions of labor, land, and resources. The labor factor is expressed by the number of agricultural employees, which is equal to the number of people employed in the primary sector in the region multiplied by the share of value added in agriculture in value added in the primary sector. The land indicator is represented by the planting area of crops, which can better reflect the situation of multiple cropping in different regions. The input of resource elements is represented by total mechanical power, fertilizer usage, and effective irrigation area. The expected output index selects the agricultural total output value (constant price in 2006) and agricultural carbon sequestration (whole-life carbon uptake of major plant species, including rice, wheat, maize, pulses, and vegetables, etc.); and the unexpected output selects agricultural carbon emissions, which are measured by agricultural materials, rice fields, and soil carbon emissions. On the one hand, agriculture has the dual effect of contributing to both carbon emissions and sequestration, carbon emission enhances the greenhouse effect and is a real pollutant, so temperature control and emission reduction are consistent with the development of green and low-carbon agriculture; on the other hand, there are many polluting behaviors in agricultural production, but it is difficult to measure them scientifically, and most of them produce greenhouse gases. Carbon emissions as a non-desired output can indirectly quantify many problems.

Explanatory Variable

Some scholars use the per capita cultivated land area to measure farmland management scale, but to factor in issues such as idle land, multiple cropping and rural labor transfer, we use the per capita sown area to measure management scale [16], This index cannot only reflect the degree of agricultural intensification and the scale of agricultural production, but also reflect the actual utilization rate of cultivated land. Therefore, this paper uses the average sown area per laborer to characterize farmland management scale. Take the natural logarithm to represent.

Adjusting Variable

Considering the more widespread use of agricultural machinery in agricultural production, thus replacing the traditional human and animal production methods. Drawing on existing studies [47, 48], this paper uses the ratio of the area of machinery outsourcing services to the total area of crops sown in five segments: tillage, seeding, irrigation, plant protection, and harvesting.

Control Variables

In addition to the core variables of farmland management scale, we also selected the control variables of disaster degree (*Disa*), agricultural industrial structure (*Indus*), income structure (*Ins*), trade dependence (*Trade*), labor culture level (*Edu*), and financial support for agriculture (*Fina*) [22, 49, 50]. Table 1 shows descriptive statistics of the main variables.

Table 1. Variable descriptive statistics.

Type	Variable name	Variable definition	Mean	SD	Min	Max
Explained variable	*Aee*	Consider carbon emission and carbon sinks.	0.762	0.248	0.409	1.211
Explanatory variable	*Lnscale*	Natural logarithm of crop area sown per capita.	1.250	0.581	0.517	4.113
Control variables	*Disa*	The proportion of affected area of crops.	0.201	0.147	0.000	0.696
	Indus	The proportion of grain sown.	0.662	0.137	0.357	0.971
	Ins	Proportion of urban and rural per capita disposable income.	2.803	0.531	1.845	4.593
	Trade	Proportion of total import and export trade of agricultural products in agricultural GDP.	0.294	0.787	0.003	6.071
	Edu	Average years of education in rural areas.	7.646	0.667	5.489	9.941
	Fina	The proportion of government funds supporting agriculture and rural areas.	0.106	0.034	0.018	0.190
Adjusting variable	*Services*	Extent of agricultural productive service outsourcing.	0.427	0.177	0.041	0.811

Data Sources

This paper takes 30 provinces in China as the research subject and analyses the available data, excluding Hong Kong, Macao and Taiwan and Tibet. According to the Chinese Statistical Division Standard, the study provinces are divided into three regions. It is important to note that a milestone in agricultural development occurred in 2006 and overlaps with the sample interval set (2006-2019): the abolition of the Agricultural Tax Regulations in and the complete abolition of agricultural tax. The total import and export volume of agricultural products comes from the Monthly Statistical Report of Import and Export of Agricultural Products in China; and other data come from the China Statistical Yearbook, the China Agricultural Yearbook, the China Rural Statistical Yearbook, the China Population and Employment Statistical Yearbook, the China Agricultural Machinery Industry Yearbook and statistical yearbooks of various provinces and cities. The missing data are filled via the interpolation method.

Results and Discussion

The Estimates of Agricultural Eco-Efficiency

Following the Super-SBM model, Matlab2020b software is used to measure the agricultural eco-efficiency per province in China from 2006 to 2019. The specific results are shown in Fig. 1 and Table 2.

Overall Analysis of Agricultural Eco-Efficiency

From 2006 to 2019, agricultural eco-efficiency showed an upward trend, with the efficiency value increasing from 0.720 in 2006 to 0.843 in 2019, and an average annual growth rate of 1.28%. The median and mean values of agricultural eco-efficiency are in the range of 0.6 to 1.0, with the maximum value fluctuating down and then stabilizing between 1.1 and 1.3, and the minimum value fluctuating up between 0.4 and 0.5. Although overall efficiency needs to be improved, the growth rate accelerated after 2013 as a matter of fact. This shows that with the implementation of the rural revitalization strategy, agricultural and rural reforms have made great strides to improve the agricultural environment and production efficiency.

Regional Differentiation Analysis of Agricultural Eco-Efficiency

According to the regional divisions of the National Bureau of Statistics, there are significant differences in agricultural eco-efficiency across the eastern, central, and western regions according to the results in Table 2.

From 2006 to 2019, the average efficiency in the eastern region was the highest (0.885), which was much higher than the national average (0.762), followed by the central region (0.697) and the western region (0.686). This is primarily due to the fact that the eastern region possesses a strong policy environment and superior resource conditions and economic foundations. The eastern region therefore has greater support in the green transformation of agricultural production, and benefits from the effects of new technology on improving agricultural production most clearly. Compared with the eastern region, the efficiency of agricultural green production in the central and western regions is still relatively low. The regions struggle with a great demand for agricultural resources, and agricultural technology lags behind, so agriculture needs to be further transformed to encourage intensification.

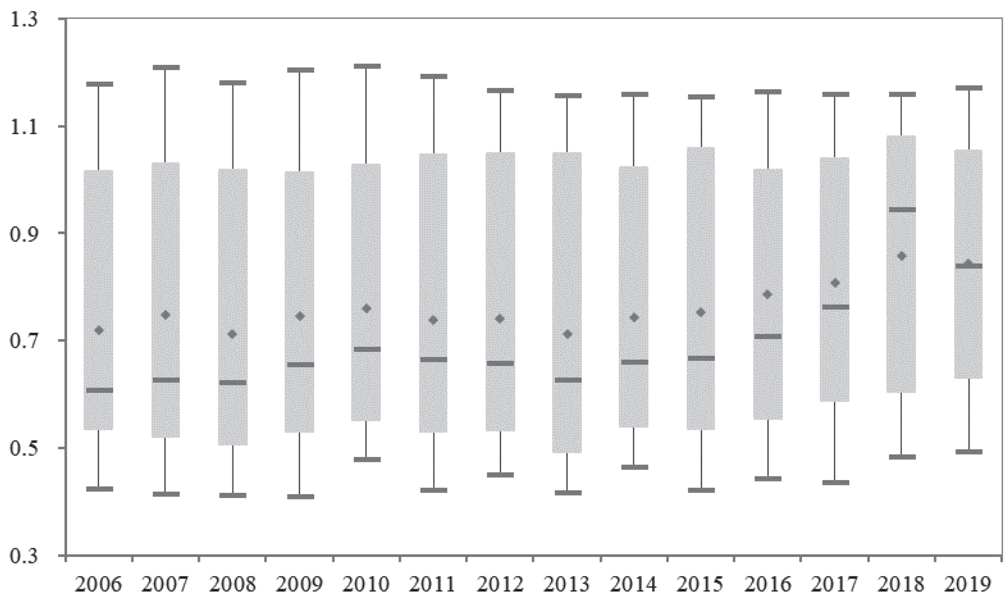

Fig. 1. Box line diagram of agricultural eco-efficiency in China from 2006 to 2019.

Table 2. Agricultural eco-efficiency per provinces in major years.

Area	2006	2009	2012	2015	2018	2019	Mean
Beijing	1.167	1.188	1.147	1.155	1.079	1.048	1.146
Tianjin	0.587	0.608	0.630	0.699	1.060	1.062	0.746
Hebei	0.572	0.617	0.643	0.636	0.740	0.692	0.645
Shanxi	0.454	0.409	0.499	0.460	0.603	0.544	0.484
Inner Mongolia	0.582	0.647	0.635	0.665	0.797	0.739	0.648
Liaoning	1.008	0.892	1.038	1.052	1.086	1.111	1.031
Jilin	1.107	1.054	1.083	1.117	1.113	1.153	1.106
Heilongjiang	1.044	1.087	1.121	1.143	1.158	1.171	1.115
Shanghai	1.132	1.138	1.125	1.084	1.088	1.033	1.105
Jiangsu	0.716	0.732	0.776	1.013	1.029	1.004	0.842
Zhejiang	0.608	0.600	0.634	0.644	1.081	1.101	0.744
Anhui	0.478	0.503	0.530	0.536	0.549	0.529	0.509
Fujian	0.607	0.665	0.674	0.691	1.005	1.025	0.736
Jiangxi	0.538	0.530	0.533	0.616	0.678	0.640	0.579
Shandong	0.651	0.720	0.722	0.750	1.007	0.833	0.751
Henan	0.694	0.745	0.719	0.736	0.890	0.843	0.750
Hubei	0.545	0.498	0.510	0.532	0.561	0.528	0.517
Hunan	0.521	0.531	0.530	0.513	0.519	0.494	0.515
Guangdong	0.781	0.724	0.770	0.789	1.017	1.027	0.828
Guangxi	1.147	1.205	1.149	1.088	1.129	1.114	1.131
Hainan	1.178	1.181	1.165	1.154	1.140	1.146	1.165
Chongqing	0.529	0.633	0.648	0.670	0.688	0.659	0.643
Sichuan	0.628	0.639	0.667	0.646	0.699	0.661	0.657
Guizhou	0.567	0.497	0.478	0.490	0.561	0.551	0.510
Yunnan	0.698	0.735	0.682	0.643	0.752	0.720	0.704
Shaanxi	0.597	0.574	0.572	0.577	0.606	0.603	0.584
Gansu	0.503	0.475	0.539	0.530	1.000	0.665	0.563
Qinghai	0.491	1.001	0.449	0.422	0.484	1.044	0.579
Ningxia	0.423	0.463	0.454	0.460	0.558	0.509	0.461
Xinjiang	1.054	1.104	1.085	1.079	1.059	1.050	1.068
East	0.819	0.824	0.847	0.879	1.030	1.007	0.885
Central	0.673	0.670	0.691	0.707	0.759	0.738	0.697
West	0.656	0.725	0.669	0.661	0.758	0.756	0.686
Average	0.720	0.746	0.740	0.753	0.858	0.843	0.762

There are obvious differences in efficiency across the regions. From the perspective of provincial efficiency, only Beijing, Liaoning, Jilin, Heilongjiang, Shanghai, Guangxi, Hainan and Xinjiang all have efficiency values greater than 1 from 2006-2019, which indicates a stably achieved DEA efficacy status. This shows that the allocation of agricultural production resources in these provinces is reasonable, and environmental pollution emissions can be reasonably controlled. At the same time, there are still 22 provinces that have not reached the effective state, mainly in the central and western regions, among which Ningxia and Shanxi show a rising

Table 3. Results of benchmark regression.

Variables	(1)	(2)	(3)
Lnscale	0.428** (2.630)	0.365*** (7.686)	0.365*** (3.024)
Lnscale^2	-0.076** (-2.430)	-0.070*** (-7.329)	-0.070*** (-2.781)
Disa	—	0.002 (0.180)	0.002 (0.238)
Indus	—	-0.033 (-0.900)	-0.033 (-0.313)
Ins	—	-0.019*** (-2.620)	-0.019 (-0.876)
Trade	—	-0.025*** (-6.846)	-0.025* (-1.840)
Edu	—	0.001 (0.226)	0.001 (0.137)
Fina	—	0.309*** (3.662)	0.309 (1.663)
_cons	-0.073 (-0.348)	0.085 (0.949)	0.085 (0.437)
Fixed province	YES	NO	YES
Fixed year	YES	YES	YES
Obs	420	420	420
R-sq	0.859	0.886	0.886

t statistics are in parentheses ***p<0.01, **p<0.05, *p<0.1

trend in agricultural eco-efficiency, but the overall efficiency value is still relatively low, and the average value is below 0.5. Overall, China's agricultural eco-efficiency is on the rise, but the overall level is still not high, regional differences are large, and the task of agricultural development transformation and upgrading is still arduous.

Impacts of Expanding Farmland Operations on Agricultural Eco-Efficiency

Benchmark Regression Analysis

The regression results of the hypotheses are reported in Table 3. In column (1), the core explanatory variables are included while controlling for year and region, revealing an initial indication of a potential non-linear association between the expansion of agricultural eco-efficiency and agricultural eco-efficiency itself. The addition of control variables in columns (2) and (3), which account for time fixed effects and time and region fixed effects, respectively, did not alter the direction or significance of the explanatory variables. Furthermore, the R2 value increased, indicating a better fit of the model. The regression coefficients are 0.365 and -0.070 respectively, both significant at the 1% statistical level, which proves the inverted U-shaped relationship between farmland operation scale and agricultural eco-efficiency, and this result confirms the effectiveness of playing a variety of moderate scale operation on green development, and hypothesis 1 is confirmed. This is consistent with Ma et al. (2019) [16] and Wang et al. (2017) [51]. The value of farmland operation scale at the inflection point is 1.356 ha/person, which has a significant positive relationship with agricultural eco-efficiency when the farmland operation scale is smaller than this value; when the farmland operation scale exceeds the inflection point, it inhibits the growth of agricultural eco-efficiency. This indicates that the expansion of farmland operation scale helps to realize resource integration and effective division of labor, and promotes the improvement of agricultural eco-efficiency. However, the scale of farmland operation should not be large, and at the same time, farmland transfer will also lead to changes in the structure of agricultural inputs. Farmers simply increase the application of chemical resources such as chemical fertilizers and pesticides in pursuit of high yields, which will intensify the environmental load of agroecosystems. Zhang et al. (2022) noted that the expansion of farmers' operation scales does not necessarily improve their allocative efficiency, but increases their input of chemical fertilizer and other elements, which may lead to agricultural non-point source pollution [52]. Therefore, H1 is validated.

Endogeneity Test

Although the expansion of farmland operation scale has an impact on agricultural eco-efficiency, agroecology will also improve due to the development of industry and technology, which will also promote the expansion of operation scale by operators. In other words, the expansion of farmland operation scale may be the reason for the improvement of agricultural production efficiency, that is, reverse causality. In addition, there are omitted variables that affect the expansion of farmland operation scale and agricultural eco-efficiency.

This section aims to establish a causal relationship between the expansion of farmland operation scale and agricultural eco-efficiency, by incorporating instrumental variables to mitigate the possible issues of reverse causality and omitted variables. Following the prior literature [53], this study selects as an instrumental variable the product of the proportion of households implementing the joint production responsibility system in each province in 1983 and the proportion of urban population in each province in each year. On the one hand, the historical data of the proportion of households implementing the joint production contract responsibility system in 1983 in each province will not have an impact on the agricultural eco-efficiency in recent years and is exogenous. On the other hand, this variable has a high correlation with the scale of farmland operation and the progress of the implementation of the joint production contract responsibility system in the early years, to a certain extent, reflects the local land policy tendency and has an impact on the current change of farmland transfer policy, which in turn The scale of farmland operation is affected. Considering that this indicator is cross-sectional data, the product of this indicator and the proportion of urban population is used as the instrumental variable. Table 4 reports the results of the test, with model (1) as the first stage of the instrumental variable model and model (2) as the second stage. In the first stage, the scale of farmland operation is highly correlated with the instrumental variable. In the second stage, there is still a highly significant inverted U-shaped relationship between farmland operation scale and agricultural eco-efficiency, which indicates that the baseline regression results are still robust after excluding endogeneity.

Robustness Test

In order to further test the robustness of the above results, this paper carries out the following robustness tests: First, select sub-samples. Considering that the agricultural form and administrative status of Beijing, Tianjin and Shanghai are different from those of other regions, it may cause errors to include them in the regression results. The data on Beijing, Tianjin and Shanghai has been deleted, and the samples of the remaining 27 regions are used for the analysis, the results are shown in column (3) of Table 4. Second, considering that agricultural eco-efficiency is greater than 0, which is a restricted dependent variable, the Tobit model is used to construct an econometric model of the impact of farmland management operations, and the results are shown in column (3) of Table 4. The results show that no matter what tests are taken, there is a significant inverted U-shaped relationship between both farmland operation scale and agricultural eco-efficiency, which proves that the conclusions obtained in this paper are robust.

Heterogeneity Analysis

1. Heterogeneous impact before and after the reform of the separation of ownership rights, contracting rights and management rights (abbreviated "separation of the three rights "). The reform of "separation of the three rights" implemented in China in 2014 has promoted the transfer of farmland to a large extent and expanded the scale of farmland management. To examine

Table 4. Endogeneity test and robustness analysis.

Variables	(1) *Landscale*	(2) *Aee*	(3) *Aee*	(4) *Aee*
Landscale	—	0.949*** (4.275)	0.207** (2.194)	0.360*** (7.819)
Landscale^2	—	-0.184*** (-4.212)	-0.045* (-2.034)	-0.068*** (-7.422)
IV	5.188*** (4.573)	—	—	—
Control variables	YES	YES	YES	YES
Fixed effects	YES	YES	YES	YES
Obs	420	420	378	420
R-sq	0.998	0.984	—	0.986

t statistics are in parentheses ***p<0.01, **p<0.05, *p<0.1

whether the impact of farmland management scale on agricultural eco-efficiency differs before and after the reform, this study adopts 2014 as the cut-off year for the regression analysis. Results from models (1) and (2) in Table 5 reveal a significant inverted U-shaped relationship between farmland management scale and agricultural eco-efficiency. However, the non-linear effect of farmland management scale on agricultural eco-efficiency is larger and more significant after the reform of "separation of the three rights", based on regression coefficients and their significance. After the separation of the three rights, the efficiency of agricultural investment and agricultural production has been improved [54]. These findings suggest that clear property rights create a more stable market for farmland transfer, which can give better play to the advantage of scale and thus promote the improvement of agricultural eco-efficiency.

2. The effect of inter-regional heterogeneity. Given the vast geographical size of China, there exist significant regional differences in terms of topography, natural climate, and other resource endowments, thus necessitating regression analysis conducted by region to account for this variation. As the findings in Table 5 reveal, the relationship between farmland operation scale and agricultural eco-efficiency varies considerably across regions. Specifically, in the east and central regions, a significant inverted U-shaped nonlinear relationship between farmland operation scale and agricultural eco-efficiency, which strongly passes the significance test at the 1% level. In the western region, the impact results are not significant. The possible reason for this is that the east and central regions have the advantages of technology and resources, and the market for farmland transfer is more well developed, which has a more significant effect on agricultural eco-efficiency.

Testing the Moderating Effect of Service Outsourcing

As previously mentioned, the top-level development of rural policy clearly requires the development of multiple forms of moderate scale operation, which is both supportive of promoting the scale operation of farmland and aims to achieve a response of service scale operation through service outsourcing, and strengthening social services have become a strategic focus to promote agricultural modernization. With the advancement of socialized agricultural services, the degree of adoption of various service outsourcing by farmers has been increasing. Therefore, this study seeks to investigate whether the impact of farmland operation scale on agricultural eco-efficiency change under the regulation of service outsourcing, and test hypothesis 2 regarding the moderating effect of service outsourcing. To achieve this, the paper introduces a cross-product term to the model for analysis, and the results are presented in Table 6.

Based on the results, it is evident that the inverted U-shaped relationship between farmland operation scale and agricultural eco-efficiency remains significant even after integrating the product terms of the primary and secondary terms of service outsourcing and farmland operation scale. Further analysis reveals that the regression coefficients of the product terms are -0.480 and 0.100, respectively, both of which are statistically significant at the 1% level. The findings suggest that the moderating effect of service outsourcing makes the inverted U-shaped relationship less steep. In essence, a high degree of service outsourcing can enhance the positive impact of farmland operation scale on agricultural eco-efficiency and the negative impact of expanding farmland transfer scale on agricultural eco-efficiency. The reason is that socialized agricultural services integrate the needs of scattered farmers, effectively achieve economies of scale and scope, share the investment risk of agricultural technology or equipment, and can promote farmers' green agricultural production [39]. In addition, as the results of Chen (2022) [55], agricultural social services can significantly reduce the carbon intensity of agriculture by providing multiple services. In addition, receiving external training services can also increase farmers' willingness to produce green [56]. Therefore, H2 is validated.

Table 5. Heterogeneity analysis.

Variables	(1) 2006-2013	(2) 2014-2019	(3) East	(4) Central	(5) West
Landscale	0.171^{**}(2.248)	0.332^{***} (3.624)	0.966^{***} (4.566)	0.352^{***} (5.630)	0.091 (1.234)
Landscale^2	-0.038^{**} (-2.167)	-0.058^{***} (-3.410)	-0.194^{***} (-3.993)	-0.062^{***} (-5.405)	-0.023 (-1.576)
Control variables	YES	YES	YES	YES	YES
Fixed effects	YES	YES	YES	YES	YES
Obs	240	180	154	112	154
R-sq	0.898	0.841	0.851	0.983	0.968

t statistics are in parentheses $^{***}p<0.01$, $^{**}p<0.05$, $^{*}p<0.1$

Table 6. Results of the test for moderating effects.

Variables	(1) *Aee*	(2) *Aee*
Landscale	0.365*** (3.024)	0.567*** (3.308)
Landscale^2	-0.070*** (-2.781)	-0.112*** (-3.370)
Servcices	—	0.568* (1.736)
Servcices×*Landscale*	—	-0.480* (-1.878)
Servcices×*Landscale*^{2}	—	0.100* (2.039)
_cons	0.085 (0.437)	-0.161 (-0.613)
Control variables	YES	YES
Fixed effects	YES	YES
Obs	420	420
R-sq	0.886	0.891

t statistics are in parentheses ***p<0.01, **p<0.05, *p<0.1

Conclusions and Policy Implications

Conclusions

Using panel data of 30 provinces in mainland China from 2006 to 2019, this paper empirically analyzes the nonlinear relationship between farmland operation scale and agricultural eco-efficiency on the basis of measuring agricultural eco-efficiency considering agricultural carbon emissions and agricultural carbon sinks, and examines the moderating role of service outsourcing in it. The results conclude as follows: First, China's agricultural eco-efficiency shows an upward trend with an average annual growth of 1.28%, but the overall efficiency level is still not high and there is still much room for improvement. Second, the scale of farmland operation and agricultural eco-efficiency shows a significant inverted U-shaped relationship non-linear relationship, and the scale of farmland operation at the inflection point is 1.356 ha/person. Third, outsourcing of services plays a significant moderating effect, and the higher the degree of outsourcing of services, the flatter the curve of the above inverted U-shaped relationship. Fourth, the non-linear relationship between the scale of agricultural land and agricultural eco-efficiency has become more significant after the reform of "separation of three rights" and in the east and central regions.

Policy Implications

According to the above research conclusions, the following policy suggestions are put forward:

First, the promotion of the green development of agriculture as a whole is paramount. At present, the agricultural eco-efficiency in China is not high overall. Considering the goal of "carbon neutrality and carbon peaking", all localities should measure carbon emissions in agricultural production, continuously increase the application of agricultural green technologies, and vigorously encourage the shift toward green ecology. Moving forward, all localities must necessarily respect the law of agricultural green development, optimize their assessment systems for agricultural development, consider the economic and environmental effects of green development, and give full play to developing agricultural versatility. All localities should combine resource endowment, industrial base and carbon emission reduction potential, should formulate differentiated agricultural industry development policies, make proper use of various policy tools, and pay close attention to policy implementation. The eastern region, especially, should play an active role in the "demonstration effect" by sharing their successful practices, while the central and western regions should strengthen their focus on the "catch-up effect", minimize their lag in green production efficiency in comparison to the eastern region, avoid the recurrence of "pollution first, then treatment", and concertedly choose green and efficient agriculture.

Second, we should promote the orderly transfer of rural land. Promoting farmland circulation is an effective way to begin solving the problems of low agricultural production efficiency and challenging management of resources and climate. With the migration of the urban and rural population and the evolution of village attributes, there is still room for improvement in the proportion of rural land transfer in China. The market-oriented transfer mechanism is imperfect, and some rural land transfer remains in the state of spontaneous transfer between farmers, which affects the improvement of agricultural eco-efficiency. We must continue to deepen the reform of the rural land system, implement the "Administrative Measures for the Transfer of Rural Land Management Rights", ease the institutional constraints on the orderly transfer of farmland, consolidate and expand land confirmation, and effectively improve the ability to trade farmland. It is also necessary to improve the rural land transfer trading market, develop the relevant system of "separation of powers", realize the diversification of transfer methods and business entities, and amplify the efficiency of agricultural green production. Finally, future policy and government action should aim to strengthen rural land remediation and high-standard farmland construction, guide qualified areas to carry out "exchange and land consolidation", create centralized contiguous fields, improve infrastructure such as farmland water conservancy, and consolidate the foundation of green and efficient agricultural management.

Third, we should promote the outsourcing of agricultural production services. According to the previous study, service outsourcing has a significant moderating effect on the inverted U-shaped relationship between farmland operation scale and agricultural eco-efficiency, and the inverted U-shaped curve becomes flatter under the moderating effect of service outsourcing, that is, the high level of service outsourcing expands the scope of the positive effect of farmland transfer scale on agricultural eco-efficiency and alleviates the inhibiting effect of expanding farmland transfer scale on agricultural eco-efficiency. Therefore, it is necessary to play the role of policy regulation to support various subjects to vigorously develop agricultural productive services; at the same time, it is necessary to focus on meeting the business needs of small farmers and new agricultural business subjects, ensuring dynamic matching with the size of business scale, and focusing on supporting productive services that make up for the shortcomings of modern agricultural construction as well as providing green technology and sustainable resource utilization.

Limitations and Prospects of Research

Although this study has made some progress, there are still shortcomings to the research. First, due to the limitations of data collection, this paper analyses the data from 2006 to 2019 only. In follow-up research, we will carry out a wider breadth of empirical analysis. Second, this paper mainly carries out empirical analysis from the macro level, but fails to explore the impact from the micro perspective. Follow-up research will be carried out from the perspective of farmers' behavior to address this gap.

Acknowledgments

This work was supported by the National Social Science Foundation of China (Grant No. 20BJY143) and Anhui Province Philosophy and Social Science Planning Program (Grant No. AHSKF2020D04).

Conflict of Interest

The authors declare no conflict of interest.

References

1. LIU Y.S., LI J.T., YANG Y.Y. Strategic adjustment of land use policy under the economic transformation. Land Use Policy, **74**, 5, **2018**.
2. DENG X.Z., GIBSON J. Improving eco-efficiency for the sustainable agricultural production: A case study in Shandong, China. Technological Forecasting and Social Change, **144**, 394, **2019**.
3. LIU Y., ZOU L., WANG Y. Spatial-temporal characteristics and influencing factors of agricultural eco-efficiency in China in recent 40 years. Land Use Policy, **97**, 104794, **2020**.
4. SU Y., HE S., WANG K., SHAHTAHMASSEBI A.R., ZHANG L.P., ZHANG J., ZHANG M., GAN M.Y. Quantifying the sustainability of three types of agricultural production in China: An emergy analysis with the integration of environmental pollution. Journal of Cleaner Production, **252**, 119650, **2020**.
5. SUN B., ZHANG L.X., YANG L.Z., ZHANG F.S., NORSE D., ZHU Z.L., Agricultural Non-Point Source Pollution in China: Causes and Mitigation Measures. Ambio, **41**, (4), 370, **2012**.
6. WANG Y., ZHU Y., ZHANG S., WANG Y. What could promote farmers to replace chemical fertilizers with organic fertilizers? Journal of Cleaner Production, **199**, 882, **2018**.
7. ZHANG L., PANG, J.X., CHEN X.P., LU Z.M.N. Carbon emissions, energy consumption and economic growth: Evidence from the agricultural sector of China's main grain-producing areas. Science of the Total Environment, **665**, 1017, **2019**.
8. WU H.Y., SIPILAINEN T., HE Y., HUANG H.J., LUO L.X., CHEN W.K., MENG Y. Performance of cropland low-carbon use in China: Measurement, spatiotemporal characteristics, and driving factors. Science of the Total Environment, **800**, 149552, **2021**.
9. HE P., ZHANG J., LI W., The role of agricultural green production technologies in improving low-carbon efficiency in China: Necessary but not effective. Journal of Environmental Management, **293**, 112837, **2021**.
10. ZHANG Y., LONG H., LI Y., GE D., TU S. How does off-farm work affect chemical fertilizer application? Evidence from China's mountainous and plain areas. Land Use Policy, **99**, 104848, **2020**.
11. REN C., SHEN L., GRINSVEN H.V., REIS S., GU B. The impact of farm size on agricultural sustainability. Journal of Cleaner Production, **220**, 357, **2019**.
12. JU X., GU B., WU Y., GALLOWAY J.N. Reducing China's fertilizer use by increasing farm size. Global Environmental Change, **41**, 26, **2016**.
13. WU Y.Y., XI X.C., TANG X., LUO D.M., GU B.J., LAM S.K., VITOUSEK P.M., CHEN D. Policy distortions, farm size, and the overuse of agricultural chemicals in China. Proceedings of the National Academy of Sciences of the United States of America, **115**, 7010, **2018**.
14. WANG L., WEI D.D. Legal Regulation of Environmental Problems in Rural Land Circulation. Journal of University of Jinan (Social Science Edition), **31**, 14-21+157, **2021**.
15. CHENG X.Y., XIN G.X., CHEN R.R., LI C.H. Impact of farmland transfer on agroecosystem. Chinese Journal of Eco-Agriculture, **24**, 335, **2016**.
16. MA X.L., CHE X.C., LI N., TANG L. Has cultivated land transfer and scale operation improved the agricultural environment? An empirical test on impact of cultivated land use on agricultural environment efficiency. China Land Science, **33**, 62, **2019**.
17. MOLLER A., SCHALTEGGER S. The sustainability balanced scorecard as a framework for eco-efficiency analysis. Journal of Industrial Ecology, **9** (4), 73, **2005**.
18. HUANG J.H., YANG X.G., CHENG G., WANG S.Y. A comprehensive eco-efficiency model and dynamics of regional eco-efficiency in China. Journal of Cleaner Production, **67**, 228, **2014**.
19. CAIADO R.G.G., DIAS R.D., MATTOS L.V., QUELHAS O.L.G., LEAL W. Towards sustainable development through the perspective of eco-efficiency-A systematic

literature review. Journal of Cleaner Production, **165**, 890, **2017**.
20. HAN Y.H., ZHANG F., HUANG L.X., PENG K.M., WANG X.B. Does industrial upgrading promote eco-efficiency? A panel space estimation based on Chinese evidence. Energy Policy, **154**, 112286, **2021**.
21. CHEN Y.F., MIAO J.F., ZHU Z.T. Measuring green total factor productivity of China's agricultural sector: A three-stage SBM-DEA model with non-point source pollution and CO_2 emissions. Journal of Cleaner Production, **318**, 128543, **2021**.
22. ZHU Y.Y., ZHANG Y., PIAO H.L. Does agricultural mechanization improve agricultural environment efficiency? Evidence from China's planting industry. Environmental Science and Pollution Research, **29** (35), 53673, **2022**.
23. CHENG C.M., LI J.Q., QIU Y.Q., GAO C.F., GAO Q. Evaluating the Spatiotemporal Characteristics of Agricultural Eco-Efficiency Alongside China's Carbon Neutrality Targets. International Journal of Environmental Research and Public Health, **19** (23), 15478, **2022**.
24. KOIRALA K.H., MISHRA A., MOHANTY, S. Impact of land ownership on productivity and efficiency of rice farmers: The case of the Philippines. Land Use Policy, **50**, 371, **2016**.
25. ZHANG J., MISHRA A.K., ZHU P.X. Land rental markets and labor productivity: Evidence from rural China. Canadian Journal of Agricultural Economics-Revue Canadienne D Agroeconomie, **69** (1), 93, **2021**.
26. LIU Y., YAN B.J., WANG Y., ZHOU Y.H. Will land transfer always increase technical efficiency in China? -A land cost perspective. Land Use Policy, **82**, 414, **2019**.
27. ARAGON F.M., RESTUCCIA D., RUD J.P. Are small farms really more productive than large farms? Food Policy, **106**, 102168, **2022**.
28. ZHANG L., LUO B.L. Agricultural reduction: Scale logic and evidence of farmers' management. Chinese Rural Economy, **2**, 81, 2020.
29. LI J.K., WANG W., LI M., LI, Q., LIU Z.M., CHEN W., WANG Y.A. Impact of Land Management Scale on the Carbon Emissions of the Planting Industry in China. Land, **11** (6), 816, **2022**.
30. SMITH L., SICILIANO G. A comprehensive review of constraints to improved management of fertilizers in China and mitigation of diffuse water pollution from agriculture. Agriculture, Ecosystems & Environment, **209**, 15, **2015**.
31. KUANG Y.P., ZHANG R. Effect of farmland transfer on the ecological efficiency of food production. China population, resources and environment, **31** (4), 172, **2021**.
32. ALI D.A., DEININGER K., GOLDSTEIN M. Environmental and gender impacts of land tenure regularization in Africa: Pilot evidence from Rwanda. Journal of Development Economics, **110**, 262, **2014**.
33. WU J.Q., WEN X., QI, X.L., FANG S.L., XU C.X. More Land, Less Pollution? How Land Transfer Affects Fertilizer Application. International Journal of Environmental Research and Public Health, **18** (21), 11268, **2021**.
34. LI F.D., REN J., WIMMER S., YIN C.B., LI Z.Y., XU C.X. Incentive mechanism for promoting farmers to plant green manure in China. Journal of Cleaner Production, **267**, 122197, **2020**.
35. LI B.W., SHEN Y.Q. Effects of land transfer quality on the application of organic fertilizer by large-scale farmers in China. Land Use Policy, **100**, 105124, **2021**.
36. FERREIRA M.D.P., FERES J.G. Farm size and Land use efficiency in the Brazilian Amazon. Land Use Policy, **99**, 104901, **2020**.
37. YUAN S.C., WANG J. Involution Effect: Does China's Rural Land Transfer Market Still Have Efficiency? Land, **11** (5), 704, **2022**.
38. ZHAO C., KONG X.Z., QIU H.G. Does the Expansion of Farm Size Contribute to the Reduction of Chemical Fertilizers? - Empirical Analysis Based on 1274 Family Farms in China. Journal of Agrotechnical Economics, **4**, 110, **2021**.
39. CHENG C., GAO Q., QIU Y. Assessing the Ability of Agricultural Socialized Services to Promote the Protection of Cultivated Land among Farmers. Land, **11** (8), 1338, **2022**.
40. QIAN L., LU H., GAO Q., LU H.L. Household-owned farm machinery vs. outsourced machinery services: The impact of agricultural mechanization on the land leasing behavior of relatively large-scale farmers in China. Land Use Policy, **115**, 106008, **2022**.
41. DENG X., XU D.D., ZENG M., QI Y.B. Does outsourcing affect agricultural productivity of farmer households? Evidence from China. China Agricultural Economic Review, **12** (4), 673, **2020**.
42. ZHENG J.G., ZHANG R.X. Can Outsourcing Reduce Pesticide Overuse? Analysis Based on the Moderating Effect of Farmland Scale. Journal of Agrotechnical Economics **2**, 16, **2022**.
43. GUO Y.H., TONG L.J., MEI L. Spatiotemporal characteristics and influencing factors of agricultural eco-efficiency in Jilin agricultural production zone from a low carbon perspective. Environmental Science and Pollution Research, **29** (20), 29854, **2022**.
44. YANG H., WANG X.X., BIN P. Agriculture carbon-emission reduction and changing factors behind agricultural eco-efficiency growth in China. Journal of Cleaner Production, **334**, 130193, **2022**.
45. KUANG B., LU X.H., ZHOU M., CHEN D.L. Provincial cultivated land use efficiency in China: Empirical analysis based on the SBM-DEA model with carbon emissions considered. Technological Forecasting and Social Change, **151**, 119874, **2020**.
46. GAO Q., CHENG C.M., SUN G.L., LI, J.F. The Impact of Digital Inclusive Finance on Agricultural Green Total Factor Productivity: Evidence from China. Frontiers in Ecology and Evolution, **10**, 905644, **2022**.
47. LI K.L., YANG H.L. Can the Level of Agricultural Production Outsourcing Services Improve Food Production? Based on Provincial Panel Data from 2011 to 2020. Reform of Economic System, **5**, 83, **2022**.
48. XUE C., SHI X.Y., ZHOU H. Influence Path of Agricultural Mechanization on Total Factor Productivity Growth in Planting Industry. Journal of Agrotechnical Economics, **10**, 87-102, **2020**.
49. HUANG X.Q., FENG C., QIN J.H., WANG X., ZHANG T. Measuring China's agricultural green total factor productivity and its drivers during 1998-2019. Science of the Total Environment, **829**, 154477, **2022**.
50. FANG L., HU R., MAO H., CHEN S.J. How crop insurance influences agricultural green total factor productivity: Evidence from Chinese farmers. Journal of Cleaner Production, **321**, 128977, **2021**.
51. WANG X.L., CHEN Y.Q., SUI P., YAN P., YANG X.L., GAO W.S. Preliminary analysis on economic and environmental consequences of grain production on different farm sizes in North China Plain. Agricultural Systems, **153**, 181, **2017**.

52. ZHANG Q., RAZZAQ A., QIN J., FENG Z.C., YE F., XIAO M.Z. Does the Expansion of Farmers' Operation Scale Improve the Efficiency of Agricultural Production in China? Implications for Environmental Sustainability. Frontiers in Environmental Science, **10**, 918060, **2022**.
53. ZHOU J.B., WANG W.B., GONG M.Y., HUANG Z.X. Land Transfers Occupational Stratification and Poverty Reduction. Economic Research Journal, **55** (06), 155, **2020**.
54. ZHOU L., SHEN K.R. Impact of the Rural Land System Reform on Rural Households' Income Growth in China: Evidence from the Three Rights Separation. Economic Research Journal, **57** (05), 141, **2022**.
55. CHEN Z.W., TANG C., LIU B., LIU P., ZHANG X.Y. Can socialized services reduce agricultural carbon emissions in the context of appropriate scale land management? Frontiers in Environmental Science, **10**, 1039760, **2022**.
56. XUE Z., LI J.Q., CAO G.Q. Training and Self-Learning: How to Improve Farmers' Willingness to Adopt Farmland Conservation Technology? Evidence from Jiangsu Province of China. Land, **11** (12), 2230, **2023**.