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RURAL ENGINEERING

The impact of agricultural comprehensive development on agro-ecological efficiency of China - evidence from perspective of scale and structure

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ABSTRACT: Promoting the agricultural sustainable development is one of the core objectives of agricultural comprehensive development (ACD), and the core of agricultural sustainable development lies in enhancing agro-ecological efficiency (AEE). Based on inter-provincial panel data from 2003-2017, the AEE was measured by a unexpected super-efficient SBM model. From the perspective of investment scale and investment structure, the impact of investment scale in ACD on AEE was examined using a panel econometric model, then characterizing the investment structure by the proportion of government funds in the investment of ACD, examining the non-linear relationship between investment structure of ACD and AEE seeking a reasonable proportion of government expenditure. Finally, a spatial econometric model was constructed to test the spatial spillover effect of the scale and structure of investment in ACD on AEE. Results showed that: (i) AEE of China is on the rise overall, but the efficiency level is still low and there is large scope for improvement. (ii) Due to the inefficient use of funds and the lag in the transformation of agricultural benefits, the scale of investment in ACD has a significant negative impact on AEE in the current period. (iii) The impact of investment structure of ACD on AEE presents a significant "inverted N" relationship, and the optimal proportion of government fund investment structure is 76.71%. The reasonable structure of investment in ACD at different food functional areas shows differences. (iv) After considering the spatial effect, the impact of ACD remains robust, but the spatial spillover effect prolongs the time lag of this impact of investment scale and starts to have a positive impact in the 2nd year after the investment. Guarantee the investment scale in ACD, reduce financial redundancy, establish a cooperation mechanism between ACD and agricultural ecological protection in neighboring areas, and increase the introduction of private capital can achieve sustainable development of agricultural economy.
Key words: agro-ecological efficiency (AEE), agricultural comprehensive development (ACD), investment scale, investment structure, Spatial lag.

O impacto do desenvolvimento agrícola na eficiência agro-ecológica da China: evidência sob a perspectiva de escala e estrutura

RESUMO: Promover o desenvolvimento agrícola sustentável é um dos objetivos centrais do desenvolvimento agrícola abrangente (ACD), e o núcleo do desenvolvimento agrícola sustentável está no aumento da eficiência agro-ecológica (AEE). Com base nos dados do painel interprovincial de 2003-2017, o AEE foi medido por um modelo SBM super-eficiente inesperado. Da perspectiva da escala de investimento e da estrutura de investimento, o impacto da escala de investimento da ACD na AEE foi examinado utilizando um modelo econométrico de painel, então caracterizado a estrutura de investimento pela proporção de fundos governamentais no investimento da ACD, examina a relação não linear entre a estrutura de investimento da ACD e da AEE para buscar uma proporção razoável dos gastos governamentais. Finalmente, um modelo econométrico espacial foi construído para testar o efeito de spillover espacial da escala e da estrutura de investimento da TDAA na AEE. Os resultados mostram isso: (i) O AEE da China está em ascensão em geral, mas o nível de eficiência ainda é baixo e há uma grande margem para melhorias. (ii) Devido ao uso ineficiente dos fundos e ao atraso na transformação dos benefícios agrícolas, a escala de investimento na TCAA tem um impacto negativo significativo na TCAA no período atual. (iii) O impacto da estrutura de investimento da DCA na AEE apresenta uma relação "N invertida" significativa, e a proporção ótima da estrutura de investimento dos fundos governamentais é de 76,71%. A estrutura razoável de investimento na TCA em diferentes áreas funcionais de alimentos mostra diferenças. (iv) Depois de considerar o efeito espacial, o impacto da TCA permanece robusto, mas o efeito de spillover espacial prolonga o tempo de atraso deste impacto da escala de investimento e começa a ter um impacto positivo no 2º ano após o investimento. Garantir a escala de investimento na TCA, reduzir a redundância financeira, estabelecer um mecanismo de cooperação entre a TCA e a proteção ecológica agrícola em áreas vizinhas e aumentar a introdução de capital privado pode alcançar o desenvolvimento sustentável da economia agrícola.
Palavras-chave: eficiência agro-ecológica (AEE), desenvolvimento agrícola abrangente (ACD), escala de investimento, estrutura de investimento, atraso espacial.

INTRODUCTION

Agriculture is a basic industry supported by the state and an important foundation for national stability and security. In the 17 global Sustainable Development Goals (SDGs) set by the United Nations, specifically, the Goal 2 is to end hunger, achieve food security and improved nutrition and promote sustainable agriculture. In the past 40 years of reform and opening up, China's agricultural economy has made great achievements, and it has raised about 18.5% of the world's population with 7.46% of the world's cultivated land. Since the 21st century, the No. 1 Central Document in China has long focused on

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the Three Rural Issues of "agriculture, rural areas and farmers" and strengthened the position of agriculture as the foundation of the economy. The central government has continued to lean toward "Three Rural" in infrastructure investment, giving priority to ensuring stable investment in "Three Rural" and promoting green development of agriculture (MINISTRY OF AGRICULTURE PRC, 2014).

To strengthen agricultural infrastructure and ecological construction, transform agricultural development mode, the Chinese central government began implementing the ACD in 1988 (SHI et al., 2016). The government set up special funds to comprehensively develop and utilize agricultural resources to improve the basic conditions of agricultural production, optimize the structure of agriculture and rural economy, improve the comprehensive agricultural production capacity and comprehensive benefits, and ultimately promote the agricultural sustainable development and agricultural modernization (MINISTRY OF FINANCE PRC, 2005). With the increasing investment in ACD, a multi-investment mechanism of national guidance and civilian-run with a public subsidy has been formed. The total investment has increased from 1.784 billion yuan in 1988 to 74.31 billion yuan in 2016, with an average annual growth rate of 13.71%, and of which the central government, local finance and self-raised funds have grown at an average annual rate of 16.35%, 14.67% and 10.89% respectively. It has laid a solid foundation for the sustainable development of the agricultural economy that ACD invests in the areas of high-standard farmland construction, irrigation and water-saving renovation, and industrialization development.

The rapid development of agricultural economy is accompanied by the industrialization and urbanization of China. But this process not only faces the increasingly prominent "Three Rural Issues", but also brings a series of problems such as ecological deterioration, environmental pollution and waste of resources. In detail, the utilization rate of chemical fertilizers and pesticides is less than 1/3, the recovery rate of agricultural film is less than 2/3, and the phenomenon of straw burning is serious, which leads to serious negative externalities of agricultural endogenous pollution and affects the sustainable development of agricultural production in China (JIN et al., 2019). Meanwhile, the Central Rural Work Conference in 2014 clearly proposed to establish a resource-saving and environment-friendly "two-type agriculture" to minimize the negative externalities of agricultural production. ACD has made a significant contribution to improving the basic conditions of agricultural production. In the context of the current agro-ecological environment facing severe conditions, agricultural economic development should maintain the overall coordination of resource consumption and ecological protection, that is, agricultural development should not only pay attention to its economic effects, but also its ecological impact. Thus, it is necessary to improve the agro-ecological efficiency (AEE). It is worth considering that, what role does investment in ACD contribute to AEE? Does larger-scale financial investment enhance AEE? Under the diversification of investment sources, what kind of investment structure can the government funds achieve the desired enhancement effect? (WU et al., 2010).

The government's investment in ACD is an important part of financial support for agriculture, and research on the relationship and impact of financial support to agriculture and agricultural production and other aspects has received extensive attention from academics. As for the research on the relationship and influence of financial support for agriculture, agricultural production and agricultural economic growth, relevant literature has carried out rich research from different perspectives, such as the impact of financial support for agriculture on Farmers' income increase (LUO & JIAO, 2014; HUANG, 2016), agricultural production (BELONGIA & GILBERT, 1990), agricultural economic growth (MATSUYAMA, 1992; TIMMER, 2008; LI et al., 2016), rural finance (WEN & DONG, 2011) and other aspects, as well as the use efficiency of funds (WANG & LI, 2016; WEN et al., 2018; BORGER & KERSTENS, 1996). In the aspect of the agricultural economic growth effect of financial support for agriculture, studies have reported that the investment of government finance in the agricultural field is effective, and it has confirmed that it has a positive effect on agricultural economic development (MOLLOT, 2003; LI & QIAN, 2004; ROSEGRANT et al., 1998; BATTESE & COELLI, 1995). But other studies have confirmed that the use efficiency of agricultural support funds is low (SERGIY, 2006; LI & OYANG, 2011; AFONSO & FERNANDES, 2006). There is an optimal value for the investment scale of financial support for agriculture on the impact of the agricultural economy (MATSUYAMA, 1990), and it is necessary to further optimize the scale and structure of financial support for agriculture.

The government's investment in ACD can improve the agricultural production conditions and promote the agricultural sustainable development by carrying out land management projects and industrial management projects. The related research pays more attention to the investment performance evaluation of ACD projects (LIN & FAN, 2009; KIRCHWEGER et al., 2015). Some studies have also pointed out that the investment in ACD has a positive role in promoting agricultural economic growth. But there are obvious differences among different provinces, and there are different investment entities, including central funds, local funds, bank loans and self-financing funds, which have stable co integration relationship with agricultural economic growth (WANG, 2010), but the impact effect is different (ZHANG, 2013). Meanwhile, the impact on agricultural economic growth is lagging (XING & DU, 2010).

It is reported that the existing literature on the impact of financial support for agriculture and ACD investment on agricultural production and agricultural economic growth has been abundant. Promoting agricultural sustainable development is one of the core objectives of ACD, yet little attention has been paid to it in the literature.

The agricultural sustainable development requires both resource conservation and environmental improvement while considering agricultural economic growth (MACRAE et al., 1993; LI & XU, 2018), which means that the relationship between agricultural factor input, agricultural output, and resources and environment must be coordinated. In other words, under a certain combination of agricultural input elements, as much agricultural output as possible can be obtained, which requires improving AEE. It emphasizes the unity of agricultural production efficiency and environmental benefits. We should not only pay attention to the economic benefits of agricultural production activities, but also pay attention to its resource and environmental constraints to achieve the win-win goal of agricultural output growth and environmental management (BURJA, 2009).

Improving AEE is an essential requirement to promote the sustainable development of agricultural production, and this is also the goal of ACD. In view of this, this paper will be based on the panel data of agricultural production from 2003-2017 in 30 provinces across China, and it is proposed to measure the AEE with a unexpected super-efficiency SBM model. From the perspective of investment scale and investment structure, establish a panel model to explore the influence of investment scale in ACD on AEE, then characterize the investment structure of ACD by the share of government investment scale and examine the nonlinear relationship between investment structure of ACD and AEE to find a reasonable investment structure. In addition, with the increasingly spatial relation between agricultural production (WU, 2010), the spatial spillover effect of ACD on AEE was further discussed through a spatial econometric model. Scientifically and reasonably discussing the complex relationship between the scale and structure of ACD investment and AEE would benefit to objectively realize the current reality of agricultural production fiscal expenditure, improve the fiscal support of agriculture policy, and grasp the direction of sustainable development of agricultural economy. It can provide reference for how agricultural engineering in other parts of the world can contribute to sustainable development.

Theoretical mechanism

The improvement of the AEE needs to balance the expected output of agriculture and the unexpected output of pollution discharge under the condition of certain production factors input. The impact of ACD on agro-ecology is to improve agricultural production conditions, optimize agricultural economic structure, and transform agricultural development methods through comprehensive development projects to establish special funds for comprehensive development, utilization and protection of agricultural resources. Its main task is to strengthen agricultural infrastructure and agricultural ecological construction, and ultimately realize sustainable agricultural development and agricultural modernization.

The mechanism and process of the impact of ACD investment on AEE is reflected in Figure 1. ACD investment projects are mainly divided into two categories: land governance projects and industrial development projects, and in recent years, the pilot project of modern agricultural park has been added, aiming to contain the ecological environment of the project area and develop high-yielding, high-efficiency, green and sustainable agriculture. Land governance projects mainly improve agricultural production conditions and farmland quality through the construction of high-standard farmland, comprehensive ecological management, and water-saving renovation of medium-sized irrigation areas, thus helping to promote agricultural production and farmland ecological improvement. Land management projects can also improve labor efficiency and agricultural production efficiency by generating surplus rural labor. Industrialization development projects mainly include construction of agricultural planting bases, construction of agricultural products processing and distribution facilities, and construction

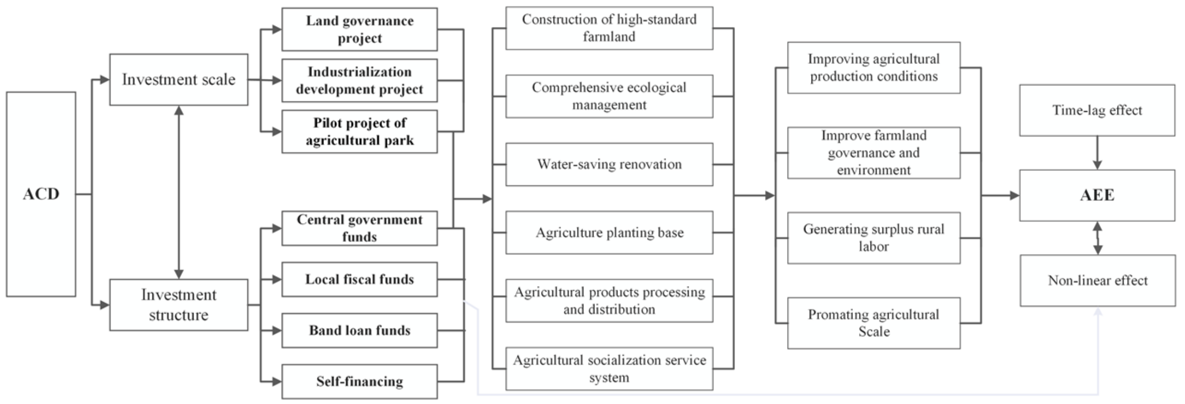

Figure 1 - The Mechanism of Investment of ACD Affecting AEE.

of agricultural socialized service systems. The agricultural production conditions are improved by adding and improving irrigation area, adding and improving flood removal area, and increasing forest network protection area, in order to promote the scale and sustainable development of agriculture. The implementation of land management projects and industrial development projects not only improves agricultural economic benefits, but also improves the ecological environment of farmland, thus promoting agricultural sustainable development and enhancing AEE. But the planning, implementation, and infrastructure of ACD projects still need a certain transformation period to produce benefits. So, the hypothesis 1 of this paper can be proposed:

Hypothesis 1: ACD investment contributes to AEE, but there is a time lag effect in the process of converting financial inputs into agricultural productivity and generating agricultural benefits.

ACD implements a diversified input mechanism of state guidance and private office assistance. Its funding sources include central fiscal funds, government fiscal funds, bank loan funds, and self-raised funds. On the one hand, the financial input of the development projects requires that the ACD funds be invested in infrastructure and ecological construction to improve agricultural production conditions; on the other hand, it requires that more economic benefits be generated while reducing negative environmental externalities, thus enhancing AEE. At present, the composition of financial inputs from different sources has experienced a change from self-financing to government funding, and diversified investment sources can guarantee the sustainable investment of funds. Taking government financial input as an example, there is a marginal decreasing effect of financial input. As the level of government financial input increases, the benefits generated will tend to stabilize, and there may be a reasonable proportion of government financial input, which may be difficult to sustainably increase if it is exceeded. It can be seen that the impact of investment structure on AEE is nonlinear, and there may be a threshold value at a certain point in time. So, hypothesis 2 is proposed accordingly.

Hypothesis 2: The impact of ACD investment structure on AEE is nonlinear, and reasonable investment structure exists.

MATERIALS AND METHODS

Samples and data sources

The sample studied in this article includes 30 provinces in China. China's ACD began in 1988, but the current statistics on the sources of capital investment in various provinces were in 2003. It is limited to data availability, so the time span is set as 2003-2017. The data of the variables involved in the article are from the "China Rural Statistical Yearbook", "China Agricultural Statistics", "China Financial Yearbook", "China agricultural comprehensive development Yearbook" and the National Bureau of Statistics data website. http://data.stats.gov.cn/easyquery.htm?cn=E0103. Due to the lack of data on the special agricultural production conditions in Tibet, Hong Kong, Macao and Taiwan, they were not included in the empirical study. Eventually, a total of 15 years of panel data were compiled.

In addition, due to the differences in agricultural production conditions and financial support in different regions, in order to gain insight into the inter-regional heterogeneity of the impact of ACD, this paper divides China into main grain producing areas, main grain sales areas, grain balance areas using different grain functional areas as criteria, where main grain producing areas include Hebei, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Jiangsu, Anhui, Jiangxi, Shandong, Henan, Hubei, Hunan, and Sichuan; the main grain sales areas include Beijing, Tianjin, Shanghai, Zhejiang, Fujian, Guangdong, Hainan, Hong Kong, Macao, and Taiwan; the grain balance areas include Shanxi, Guangxi, Chongqing, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Ningxia, Qinghai, and Xinjiang. Figure 2 shows the spatial distribution of different grain functional areas.

Figures, tables and schemes

Dependent variables

In this paper, AEE, as an explanatory variable, comprehensively reflects the coordinated and win-win relationship between the agricultural economy, resource utilization and environmental protection, and reflects the level of agricultural sustainable development. The agriculture here refers to the cropping industry in a narrow sense, and the measurement method is the super-efficiency SBM model based on undesired output (TONE, 2002; PARK, 2019; LIU & WANG, 2020). The construction of the AEE evaluation index system refers to relevant literature (TONE, 2004; WANG & ZHANG, 2016), combines the availability of data and the consistency of statistical calibers, and is based on the input of factors in the process of agricultural production, agricultural output and ecological environment impact. Based on this, for constructing an agricultural production efficiency evaluation index system, the article uses land, labor, mechanical power, irrigation, fertilizers, pesticides, etc. as agricultural input indicators, total agricultural output value as expected output indicators, and agricultural non-point source pollution emissions and carbon emissions as unexpected output. AEE index system is displayed in table 1.

Agricultural non-point source pollution emissions are mainly caused by the excessive use of chemical fertilizers, pesticides and agricultural films. This article estimates the level of agricultural non-point source pollution by using the pollution from fertilizer runoff, pesticide residues and agricultural film residues (ONGLEY, 1996; LI et al., 2011). The pollutant indicators for the calculation of the pollution from fertilizer runoff are total nitrogen (TN) and total phosphorus (TP), and the determined generating pollution units are nitrogen fertilizer, phosphate fertilizer and compound fertilizer.

The pollution unit emission factor is equal to the generating pollution factor multiplied by the fertilizer runoff rate. The generating pollution

Figure 2 - The spatial distribution of different grain functional areas in China.

Table 1 - AEE index system.

Index	Variable	Variable description	Remarks
Resources invested	Land input	Total sown area of crops/khm^2	Reflect the actual cultivated area in agricultural production
	Labor input	Agricultural employees/10,000 Capita	Calculated by first industry employees * (gross agricultural output value/gross output value of agriculture, forestry, animal husbandry and fishery)
	Mechanical investment	Total power of agricultural machinery/10,000 kW	Agricultural machinery is a representative tool of agricultural modernization
	Water input	Effective irrigation area/khm^2	Agricultural water is mainly used for irrigation, as a proxy
	Fertilizer input	Amount of agricultural chemical fertilizer applied/10,000t (reduced scalar amount)	The input of chemical fertilizers, pesticides, agricultural film, diesel, etc. are the main pollution sources in the agricultural production process
	Pesticide input	Pesticide usage/10,000 tons	
	Agricultural film investment	Agricultural film usage/10,000 tons	
	Energy input	Agricultural diesel consumption/10,000 tons	
Expected output	Agricultural output	Agricultural output value/100 million yuan	Converted to the constant price in 1978 according to the CPI index to eliminate the impact of price changes
Unexpected output	pollutant emissions	Agricultural non-point source pollution discharge/10,000 tons	Pollution from fertilizer runoff, pesticide residues and agricultural film residues
	carbon emission	Agricultural carbon emissions/10,000 tons	Carbon source coefficient refer to related literature

coefficient is calculated based on the chemical composition of chemical fertilizers: nitrogen fertilizer, phosphate fertilizer and compound fertilizer (N: P: K nutrient ratio is 1:1:1). The TN generating pollution coefficients are 1, 0 and 0.33, respectively. The TP generating pollution coefficients are 0, 0.44 and 0.15, respectively (SHI et al., 2016).

The fertilizer runoff rate in each region refers to the research of Lai etc. (LAI et al., 2004; WEI et al., 2020). The sum of total nitrogen emissions and total phosphorus emissions is the pollution from fertilizer runoff. The calculation formula for pesticide residues is: pesticide application amount × pesticide invalid utilization coefficient. The calculation formula for the amount of agricultural film residue is: agricultural film application amount × agricultural film residue coefficient. The coefficients of these two pollution emissions refer to Wu etc. and "The First National Pollution Survey: Pesticide Loss Coefficient, Farmland Film Residue Coefficient Manual", and the difference in the topography of the cultivated land in the region is taken into consideration (WU et al., 2012).

The calculation of agricultural carbon emissions refers to the carbon emissions model and calculation coefficients of related literature and selects six types of direct or indirect carbon emissions, including fertilizers, pesticides, agricultural film, agricultural diesel, irrigation power and water consumption, and plowing losses (CHEN et al., 2019). The emission coefficients of the six types of carbon sources are 0.8956 (kg/kg) for chemical fertilizers, 4.9341 (kg/kg) for pesticides, 5.18 (kg/kg) for agricultural films, 0.5927 (kg/kg) for diesel, 20.476 (kg/hm^2) for agricultural irrigation, and 312.6 (kg/hm^2) for agricultural tillage.

Independent variables

The impact of ACD investment on AEE mainly includes two aspects: investment scale and structure. Investment scale of fund input in ACD (FIACD) and Investment structure of fund in ACD (FSACD) are selected as two core independent variables for regression analysis. FIACD refers to the total investment (Billion yuan) of funds used for ACD, which includes four sources of funds: central fiscal funds, local fiscal funds, bank loans, and self-raised funds. FSACD in this article is set as the proportion of government funds in the investment scale of ACD. In other words, the sum of central fiscal funds and local fiscal funds is divided by the total capital investment (%). It can reflect the role and intensity of government action in ACD, explore the reasonable proportion of government investment to understand the efficiency of government funds.

Other variables

1. Per capita disposable income of rural residents (PDIRR, yuan). The wealth of rural residents can affect the input elements of agriculture and affect the AEE.
2. Intensity of agricultural machinery input (MII) = total power of agricultural machinery/total sown area of crops (kW/hm^2). The technical level of agriculture plays an important role in improving the AEE. Agricultural machinery investment is the most intuitive manifestation of agricultural technological progress, which has an impact on agricultural production and grain output by effectively replacing labor.
3. Multiple cropping index (MCI) = total sown area of crops/arable land area (%). Multiple cropping index refers to the average number of crops planted on the same plot of arable land in a certain period (generally 1 year), which reflects the increasing impact of land abandonment on the AEE.
4. Crop planting structure (CPS) = food crop planting area/non-food crop planting area (%). Changes in planting structure can lead to changes in the structure of agricultural input elements, which in turn affects the AEE.
5. Agricultural disaster rate (ADR) = disaster area of crops/total sown area of crops (%). The agricultural production process is greatly affected by natural conditions, which are used to reflect the impact of natural disasters on the AEE.
6. Urbanization level (URBAN): population urbanization rate = urban population/year-end permanent population (%). The development of urbanization attracts rural labor to transfer to non-agricultural sectors, which will indirectly affect agricultural production and the ecological environment. Descriptive statistics for each variable are reported in table 2.

Model pecification

Baseline model

The benchmark model on which the panel econometric model relies in this paper is the random regression impact model, STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology):

$I = aP^b A^c T^d e$. The model usually takes the logarithmic form: $\ln I = \ln a + b \ln P + c \ln A + d \ln T + \ln e$. P、A、T denotes population, affluence and technology level, respectively. b、c、d are the elasticity coefficients of P、A、T respectively. The model discards the assumption of unit elasticity and adds randomness to facilitate empirical testing. This paper examines the effect of investment in ACD on AEE through the STIRPAT model. Agro-ecological efficiency (AEE) is the explanatory variable, Investment in agricultural comprehensive development (FIACD) is the core explanatory variable, per capita Disposable Income of Rural Residents (pDIRR) characterizes affluence, and Mechanical Input Intensity (MII) reflects technology level. The standard STIRPAT model was extended by introducing other factors that affect AEE.

$$\ln AEE_{it} = \beta_0 + \beta_1 \ln FIACD_{it} + \beta_2 \ln PDIRR_{it} + \beta_3 \ln MII_{it} + \beta_4 \ln MCI_{it} + \beta_5 \ln CPS_{it} + \beta_6 \ln ADR_{it} + \beta_7 \ln URBAN_{it} + \varepsilon_{it} \tag{1}$$

Among them, $\beta_0 \sim \beta_7$ is the estimated coefficient of each variable, *i* is the area cross section, *t* is the time, and ε_{it} is the random interference term.

In addition, considering that there is a time lag effect in the transformation of FIACD into actual agricultural production capacity and comprehensive benefits, a lag term of investment scale will be added to the model regression process for comparative analysis.

To examine the non-linear relationship between FSACD and AEE. Based on the random effect of panel econometric model, we take logarithms of independent variables to eliminate their heteroskedasticity and then add the quadratic and tertiary terms of *lnFSACD* in order to find a reasonable investment structure of government funds (Quadic term as an example):

$$\ln AEE_{it} = \beta_0 + \beta_1 \ln FSACD_{it} + (\beta_2 \ln FSACD_{it})^2 + \beta_3 \ln PDIRR_{it} + \beta_4 \ln MII_{it} + \beta_5 \ln MCI_{it} + \beta_6 \ln CPS_{it} + \beta_7 \ln ADR_{it} + \beta_8 \ln URBAN_{it} + \varepsilon_{it} \tag{2}$$

Spatial econometric model

Agricultural ecology is not isolated in space, but it is heterogeneous. The closer the geographical distance means that the closer inter-regional association. Thus, if the econometric model ignores the spatial correlation between regions, the estimation results may be biased and inconsistent (ANSELIN, 1988). With the improvement of China's agricultural market economy and the expansion of regional openness, the spatial mobility of agricultural production factors has become more frequent (WU, 2010). There are heterogeneities in agricultural

Table 2 - Descriptive statistics of variables.

Variables	Abbr	Units	Sample size	Average	S.D.	Min	Max
agro-ecological efficiency	AEE	-	420	0.536	0.225	0.239	1.073
Investment Scale of ACD (Fund Input)	FIACD	Billion yuan	420	14.854	9.297	2.180	57.220
Investment Structure of ACD (Fund Structure)	FSACD	%	420	68.817	13.050	29.990	96.330
Per capita disposable income of rural residents	PDIRR	yuan	420	6994.746	4352.435	1564.66	25520.40
Intensity of agricultural machinery input	MII	kW/hm^2	420	5.628	2.662	1.644	14.156
Multiple cropping index	MCI	%	420	163.118	51.056	69.980	260.930
Crop planting structure	CPS	%	420	254.827	269.597	48.841	2224.890
Agricultural disaster rate	ADR	%	420	23.720	14.751	0.262	93.592
Urbanization	URBAN	%	420	50.158	15.046	21.047	90.300
Financial investment	FI	%	420	10.391	7.361	1.460	34.360

production conditions, element inputs, resource endowments, and location conditions in different regions, which will inevitably lead to differences in the spatial scale of AEE (ZHANG et al., 2021). It is necessary to continue to discuss the impact of ACD investment on AEE from a spatial perspective. In further discussion, the spatial lag of the two variables of AEE and investment scale was added to the econometric model to examine the impact of the scale and structure of AEE investment on ASD.

In this section, we firstly construct a Rook adjacency weight matrix with public boundaries, a geographical distance weight matrix based on the Euclidean distance of provincial capitals, and an agricultural economic distance weight matrix based on the scale of regional agricultural output value:

1. Rook adjacency weight matrix (W01). This matrix is set based on the adjacency relationship in the Rook space. When two provinces are adjacent, the element of the spatial weight matrix is set to 1. Conversely, when they are not adjacent, the element of the spatial weight matrix is set to 0 (When calculating the adjacent weight matrix, Hainan is set to be adjacent to Guangdong) (HOU & YAO, 2018).
2. Geographic distance weight matrix (Wd). The value of the element in this matrix is the reciprocal of the Euclidean distance between the capital cities of the two provinces (YU, 2017).
3. The weight matrix of agricultural economic distance (Wa). Imitating the calculation method of the general economic distance weight matrix, the value of the element in this matrix is the geographical distance weight matrix Wd multiplied by the diagonal matrix A of agricultural economic scale. The main diagonal element value in the diagonal matrix A is the ratio of the average agricultural output value of each province to the average agricultural output value of all regions during the sample study period (ZHANG & DAI, 2012).

The above three weight matrices are all processed by row standardization. The final adjusted measurement model is that:

$$\begin{aligned}\ln AEE_{it} &= \beta_0 + \rho W * \ln APE_{it} + \eta W * \ln FIACD_{it} + \beta_1 \ln FIACD_{it} + \beta_2 \ln PDIRR_{it} \\ &\quad + \beta_3 \ln MII_{it} + \beta_4 \ln MCI_{it} + \beta_5 \ln CPS_{it} + \beta_6 \ln ADR_{it} + \beta_7 \ln URBAN_{it} + \varepsilon_{it}\end{aligned} \tag{3}$$

$$\begin{aligned}\ln AEE_{it} &= \beta_0 + \rho W * \ln APE_{it} + \beta_1 \ln FSACD_{it} + (\beta_2 \ln FSACD_{it})^2 + \beta_3 \ln PDIRR_{it} \\ &\quad + \beta_4 \ln MII_{it} + \beta_5 \ln MCI_{it} + \beta_6 \ln CPS_{it} + \beta_7 \ln ADR_{it} + \beta_8 \ln URBAN_{it} + \varepsilon_{it}\end{aligned} \tag{4}$$

$W{*}lnAEE_{tt'}$ it is the spatial lag item of AEE. W is respectively W^q, W^d, W^a. ρ, η is the spatial correlation coefficient.

RESULTS

Results of FIACD on AEE

Based on the super-efficient SBM model with unexpected output, the results indicated that AEE of China has shown a fluctuating upward trend over the years, but the average is around 0.7, and the efficiency level is still low, and overall there is still more room for improving AEE. Next, the stepwise regression method is adopted to sequentially add each influencing variable to the model in order to avoid multicollinearity between variables. The specific regression results are shown in Model 1~Model 6 in table 3.

The results by gradually adding variables show that the estimated coefficients of *lnFIACD* are all negative with little change. The regression results are relatively stable, which means that the current ACD investment has

Table 3 - The regression results of the impact of FIACD on AEE.

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
ln*FIACD*	-0.039** (0.016)	-0.038** (0.015)	-0.026*** (0.016)	-0.028** (0.016)	-0.029** (0.016)	-0.029** (0.016)	-0.021 (0.018)	-0.016 (0.018)
l. ln*FIACD*							0.007 (0.019)	
*l2.*ln*FIACD*								0.013 (0.009)
ln*PDIRR*	0.109*** (0.013)	0.158*** (0.015)	0.148*** (0.015)	0.149*** (0.015)	0.135*** (0.016)	0.134*** (0.019)	0.128*** (0.023)	0.128*** (0.025)
ln*MII*		-0.151*** (0.026)	-0.157*** (0.025)	-0.156*** (0.026)	-0.152*** (0.025)	-0.151*** (0.025)	-0.149*** (0.027)	-0.147*** (0.030)
ln*MCI*			-0.129*** (0.038)	-0.130*** (0.039)	-0.129*** (0.038)	-0.129*** (0.038)	-0.134*** (0.039)	0.123*** (0.041)
ln*CPS*				-0.008 (0.019)	-0.008 (0.019)	-0.009 (0.019)	-0.008 (0.021)	-0.006 (0.025)
ln*ADR*					-0.022*** (0.006)	-0.022*** (0.006)	-0.020*** (0.007)	-0.017** (0.007)
ln*URBAN*						0.007 (0.054)	-0.002 (0.058)	-0.026 (0.062)
C	-0.316*** (0.090)	-0.499*** (0.092)	0.226 (0.337)	0.182 (0.258)	0.352 (0.258)	0.337 (0.281)	0.400 (0.316)	0.452 (0.340)
rho	0.868	0.869	0.890	0.892	0.893	0.893	0.898	0.899
LogL	440.050	456.595	462.111	462.199	468.632	468.642	432.757	397.096

Notes: ***, **, and * represent significance at 1%, 5% and 10%, respectively. Value in the bracket is standard errors.

a negative impact on the AEE. The preliminary judgment is not consistent with the expected hypothesis.

From the estimated coefficients of other variables in table 3, due to the method of gradually adding variables, it can be reported that the direction, degree and significance level of the estimated coefficients of each variable have not changed obviously. For example, in Model 8, the estimated coefficients of PDIRR, MII, MCI and ADR have all passed the significance level. Among them, only the estimated coefficient of PDIRR is positive.

Results of nonlinear impact of FSACD on AEE

The impact of investment structure on the AEE is complex. Due to the different proportions of government capital investment and other funding sources, such as bank loans and self-raised funds, and different investment directions, the impact on AEE is not exactly the same, which means that the impact of investment structure may be non-linear. Due to the lack of efficiency and time lag effect of current financial investment in ACD, in order to continue to explore the reasonable structure of investment in ACD, the quadratic and cubic terms of investment structure are gradually added to the model to explore the change law of the nonlinear relationship between them and find the optimal capital investment structure. Meanwhile, there is heterogeneity in agricultural production conditions and capital investment efforts in different grain functional areas, which is necessary to further explore the non-linear effect of investment structure on AEE (Table 4).

According to the regression results in table 4, it can be found that:

a) The regression results at the national level illustrate that the coefficient of lnFSACD is insignificant in the quadratic term and significant in the cubic term, which means that the impact of the FSACD on AEE shows a significant cubic curve relationship in the form of "inverted N". It indicated that the AEE decreases, then increases, and then decreases with the increase of the proportion of government investment in ACD. In other words, there is a certain point in time when the financial input structure of ACD has a threshold value, beyond which the AEE will turn around. By solving the inflection point of the cubic curve, it can be obtained that the lnFSACD corresponding to the turning point of the ASD is 3.93 and 4.34 respectively, and the corresponding FSACD is $e^{3.93}$=50.91(%), $e^{4.34}$=76.71(%). The FSACD of

Table 4 - Non-linear regression outputs of the impact of FSACD on AEE.

Variables	-------National level-------		Main grain producing areas		--Main grain sales areas--		---Grain balance areas---	
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
ln*FSACD*	-0.231 (0.554)	-6.931*** (0.056)	-1.061 (0.700)	27.886** (13.42)	0.004 (1.105)	-32.613** (12.583)	0.784 (0.919)	-34.709** (15.864)
$(\ln FSACD)^2$	0.028 (0.065)	1.681*** (0.079)	0.136 (0.085)	-6.966** (3.289)	-0.001 (0.132)	8.132* (4.542)	-0.099 (0.112)	8.743** (3.948)
$(\ln FSACD)^3$		-0.136*** (0.019)		0.579** (0.268)		-0.675* (0.345)		-0.732** (0.327)
ln*PDIRR*	0.112*** (0.018)	0.113*** (0.018)	0.049* (0.029)	0.047* (0.029)	0.212*** (0.025)	0.221*** (0.026)	0.022 (0.038)	0.035 (0.038)
ln*MII*	-0.153*** (0.026)	-0.153*** (0.026)	-0.082*** (0.032)	-0.080** (0.031)	-0.476*** (0.054)	-0.484*** (0.054)	-0.015 (0.055)	-0.016 (0.054)
ln*MCI*	-0.146*** (0.037)	-0.145*** (0.037)	0.052 (0.047)	0.058 (0.047)	-0.185*** (0.050)	-0.178*** (0.050)	-0.272** (0.122)	-0.231** (0.120)
ln*CPS*	-0.001 (0.019)	-0.001 (0.019)	0.003 (0.026)	-0.004 (0.026)	-0.124*** (0.036)	-0.129*** (0.036)	-0.015 (0.048)	-0.037 (0.048)
ln*ADR*	-0.022*** (0.006)	-0.022*** (0.006)	-0.015* (0.009)	-0.015* (0.008)	-0.015** (0.007)	-0.013** (0.007)	-0.055*** (0.016)	-0.049*** (0.016)
ln*URBAN*	0.013 (0.053)	0.008 (0.054)	0.160** (0.069)	0.172** (0.068)	0.128 (0.127)	0.102 (0.126)	0.097 (0.122)	0.034 (0.123)
C	1.033 (1.153)	1.063 (1.057)	1.380 (1.537)	-37.876** (18.238)	0.700 (2.316)	46.237 (30.624)	0.025 (2.074)	47.363** (21.216)
rho	0.901	0.901	0.844	0.841	0.936	0.937	0.902	0.904
LogL	467.044	467.285	250.752	253.060	128.621	129.719	141.506	143.973

Notes: ***, **, and * represent significance at 1%, 5% and 10%, respectively. Value in the bracket is standard errors.

most provinces crossed the first turning point in 2003, and the second turning point was in 2012.

b) The regression results of each grain functional areas display that the coefficients of the cubic terms of the investment structure in the main grain sales areas and grain balance areas are significant, which all show a significant "inverted N" curve. When the proportion of government investment exceeds the second extreme point, it would lead to a decline in AEE. By solving the extreme points of the cubic curve, we can obtain the lnFSACD corresponding to the inflection point of AEE turns can be obtained respectively. Specifically, the lnFSACD of main grain sales areas is 1.75 and 4.16, and the corresponding FSACD is $e^{1.75}$=5.75%, $e^{4.16}$=64.07%. As a result, the reasonable range for the proportion of government capital investment is (5.75%, 64.07%). Undoubtedly, it is the optimal fund structure when the proportion of government capital reaches 64.07%. In the grain balance areas, the inflection point of lnFSACD is 3.76 and 4.21, and the corresponding FSACD is $e^{3.76}$=42.95% and $e^{4.21}$=67.36%. The reasonable range for the proportion of government capital investment is (42.95%, 67.36%), and it is the optimal government capital fund proportion when FSACD reaches 67.36%. In contrast, the influence of the FSACD on AEE presents an "N" curve in the main grain producing areas, which means that with the increase in the proportion of government investment in ACD, the AEE shows a trend of first rising, then falling, and then rising. The lnFSACD corresponding to the extreme point is 3.88 and 4.14 respectively, and the FSACD is $e^{3.88}$=48.42% and $e^{4.14}$=62.80%. When the proportion of government investment is higher than 62.80%, the AEE will be promoted. In fact, the current provinces have successively exceeded 62.80% of their input since 2010.

Spatial spillover effects of investment scale and structure

First, the spatial relevance of AEE is tested. Based on the three spatial weight matrices, the *Moran's I* index distribution range is 0.1132-0.2763, and all have passed the significant test, which indicates that the AEE has a significant positive spatial correlation. It is feasible to introduce spatial lag in the panel measurement model. Table 5 and table 6 report the regression results based on the spatial perspective.

The estimated coefficients of the AEE with the addition of the spatial lag term are all extremely

Table 5 - Regression results of FIACD with spatial lag.

Variables		--Rook adjacency weight matrix--			Geographic distanceweight matrix			Agricultural economic distance weight matrix		
		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
FIACD	W^{*}ln*AEE*	0.215*** (0.001)	0.227*** (0.000)	0.225*** (0.001)	0.705*** (0.000)	0.769*** (0.000)	0.821*** (0.000)	0.933*** (0.000)	1.012*** (0.000)	1.043*** (0.000)
	W^{*}ln*FIACD*	0.001 (0.840)	0.001 (0.909)	0.001 (0.768)	0.004 (0.197)	0.004 (0.265)	0.004 (0.264)	0.005*** (0.000)	0.005*** (0.000)	0.005*** (0.000)
	ln*FIACD*	-0.034** (0.026)			-0.027* (0.083)			-0.025* (0.089)		
	l. ln*FIACD*		-0.010 (0.803)			-0.006 (0.727)			-0.004 (0.478)	
	l2. ln*FIACD*			0.015 (0.509)			0.013 (0.462)			0.009 (0.602)

Notes: ***, **, and * represent significance at 1%, 5% and 10%, respectively. Value in the bracket is standard errors.

significant. The coefficient of AEE was the largest under the agricultural economic distance weight matrix, the second largest under the geographical distance weight matrix, and the smallest under the neighboring weight matrix, which is due to the fact that the agricultural economic distance weight matrix takes into account not only the geographical location between regions, but also the difference in agricultural economic strength between regions, thus implying that the neighboring regions' AEE has a spatial spillover effect on the region. The coefficients of the spatial lag term of investment scale pass the significance test and are positive only under the agricultural economic distance weights. The coefficient of the current period of investment scale in the spatial perspective is significantly negative, and the coefficient of the second lag is positive, which is more consistent with the results of the previous analysis.

From the regression results of investment structure, the estimated coefficients of AEE with the inclusion of the spatial lag term are equally significant. That is, AEE exhibits steady spatial spillover effects. The quadratic curve forms under different weight matrices were not significant, and only the cubic curve forms under the agricultural economic distance weight matrix passed the significance test, which also confirmed that the investment structure of agribusiness development and agricultural production efficiency showed an inverted-N curve relationship. By solving the inflection points of the three curves, we can obtain the investment structure lnFSACD corresponding to the inflection points where the AEE takes a turn for 3.84 and 4.29, respectively, and the corresponding FSACD is $e^{3.84}$=46.53%, $e^{4.29}$=72.97%, and the year corresponding to the second inflection point is about 2011.

Table 6 - Regression results of FSACD with spatial lag.

Variables		Rook adjacency weight matrix		Geographic distance weight matrix		Agricultural economic distance weight matrix	
		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
FSACD	W^{*}ln*AEE*	0.022 (0.712)	0.023 (0.688)	0.552 (0.003)	0.575*** (0.002)	0.628*** (0.000)	0.655*** (0.000)
	ln*FSACD*	-0.295 (0.705)	-19.137 (0.171)	-0.169 (0.825)	-22.078 (0.109)	-0.006 (0.994)	-23.415* (0.088)
	$(\ln FSACD)^2$	0.035 (0.712)	4.685 (0.174)	0.021 (0.824)	5.428 (0.110)	0.001 (0.996)	5.779* (0.086)
	$(\ln FSACD)^3$		-0.381 (0.177)		-0.444 (0.111)		-0.474* (0.086)

Notes: ***, **, and * represent significance at 1%, 5% and 10%, respectively. Value in the bracket is standard errors.

DISCUSSION

The impact of the investment scale in ACD

The investment scale in ACD has significantly negative effect on AEE in the current period. The possible reasons are explained from the following two aspects:

a) The allocation of funds invested in that year was unreasonable and lack of efficiency, resulting in failure to effectively improve agricultural production conditions and agricultural ecological environment. Thus, based on the national ACD data statistics table, taking investment in land management projects, industrialized management projects and pilot projects in modern agricultural parks as input factors, and improving agricultural production conditions and increasing production capacity of major agricultural products as output factors in project benefits, the input-oriented DEA model with variable returns to scale has been used to simply measure the efficiency of capital use in the past 10 years (Table 7). It can be verified that both the national average efficiency and the efficiency of some provinces show that the investment in ACD in that year was inefficient and the use of funds was redundant.

b) If the investment in ACD in the current year is redundant, there would be a time lag effect in the process of transforming the investment into agricultural benefits. In order to verify the time lag effect of capital investment, the first lag term of investment scale is introduced in the model. The regression results, model 7 in table 3, show that the estimated coefficient of the investment scale of the lagging period is 0.007>0, which has a positive effect on the AEE, but it is not significant. Furthermore, the second-order lag term of the investment scale is introduced (Model 8 in table 3), the estimated coefficient of investment scale for the lag 2nd is 0.013>0, and it is also not significant. Although, the significant level of lag terms is not high, it also reflects to a certain extent that the investment in ACD fails to exert its effect in the current period. There is a time lag effect from the investment of funds in project construction to produce benefits. The use of funds can hardly be transformed into agricultural productivity in a short period of time, with a time lag of at least 2 years. This is related to the main task of ACD which refers to the strengthening of infrastructure and ecological construction, and the infrastructure construction cycle is generally longer. Moreover, it is generally related to the general 1-2 years construction period of ACD projects as required in the "National Agricultural Comprehensive Development Funds and Project Management Measures". So, hypothesis 1 is basically verified. In addition, it can be roughly judged that the investment in ACD does not positively promote the AEE in the current period, mainly due to the lack of efficiency in capital investment.

Regarding the other control variables, the increase in farmers' income promotes the off-farm transfer of rural labor on the one hand, and ensures that farmers have more funds to improve agricultural production conditions on the other. The significant negative effects of MII, MCI and ADR are explained by the fact that agricultural machinery inputs increase agricultural carbon emission through diesel consumption and agricultural film mulching.

If the potential of arable land utilization is exploited without restraint and not combined

Table 7 - Utilization efficiency of ACD funds.

Provinces	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Beijing	1	0.8742	0.5523	0.5942	1	0.6781	0.5472	0.4442	0.6140	1
Tianjin	1	1	1	1	1	1	1	1	1	1
Hebei	1	1	1	0.9775	0.7800	1	1	1	0.9402	1
Liaoning	0.6478	0.7058	0.6686	0.8157	0.9973	0.7844	0.8706	0.8542	0.8689	0.7770
Zhejiang	0.4580	0.4670	0.4653	0.5935	0.4636	0.8269	0.7969	0.7262	1	0.3435
Fujian	0.5569	0.6711	0.5364	0.7840	0.6305	1	0.7073	0.5422	0.6400	0.8848
Hunan	0.7216	0.7536	0.6401	0.7008	0.7124	0.6092	0.7711	0.7185	0.7671	0.8358
Guangdong	0.8455	0.7715	0.7148	0.8142	1	0.9640	1	0.7859	0.8918	0.9620
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Average	0.8763	0.8915	0.8408	0.8997	0.9250	0.9411	0.9184	0.8828	0.9156	0.9270

Note: Limited to space, only some provinces are listed.

with crop rotation and shifting cultivation system, while cash crops have the characteristics of short production cycle, high water and fertilizer demand and high degree of intensification, the expansion of agricultural disaster area will lead to the decline of agro-ecological efficiency, but the annual disaster area does not have regularity.

The estimated coefficients of CPS and URBAN are negative but not significant, indicating that; although, the change in cropping structure and urbanization development are not the main factors affecting AEE, they reflect their negative effects on AEE to some extent.

Reasonable investment scale of ACD

The diversification of funding sources makes the government funds of ACD not the better, but there is a certain threshold, and when government funding exceeds this threshold, it may lead to a turnaround of the impact on AEE.

To explore the reasons, in the initial stage, ACD, as a beneficial exploration of the government's fiscal support for agriculture, has less capital investment and mainly focuses on improving basic agricultural production conditions. The composition of central funds, local funds, bank loans and self-raised funds is basically maintained at the level of 1:1:1:1, and self-raised funds are the highest. The central and local governments' total fiscal investment ratio is less than 50%, and it is difficult for the fiscal capital investment ratio to play an effective role. While with continued in-depth ACD, it has begun to attach importance to agricultural production capacity and protecting the environment combined. During this period, the scale of financial investment has increased year by year. When the proportion of government financial investment is between 50.91% and 76.71%, the adjustment of agricultural structure and the advancement and extension of agricultural science and technology have mobilized the enthusiasm of local governments at all levels, rural collectives and farmers in ACD. With the continued expansion of financial investment proportion, diminishing marginal effects makes the AEE shift from an increase to a decline when the proportion of capital investment exceeds 76.71%. Above all, there is a reasonable range (50.91%, 76.71%) in the proportion of government investment in ACD, which can help promote AEE within this range. The optimal capital structure is when the proportion of government investment reaches 76.71%. There is an optimal capital structure when the proportion of government investment reaches 76.71%. In fact, the proportion of financial investment in China's ACD has reached 81.57% in 2016, which is already in the stage of diminishing marginal effects, and the capital investment structure needs to be further optimized. Thus, Hypothesis two has been verified.

The non-linear characteristics of the main grain sales areas and grain balance areas are similar to those of the whole country, but the curve characteristics of the main grain producing areas are the opposite. Demonstrably, there are some reasons for the differentiation in different grain functional areas. In the main grain sales areas, the economy is relatively developed, and the mainstay is to grow cash crops. Agricultural production conditions have become more mature, and the marginal diminishing effect is more significant. The grain balance areas are dominated by the cultivation of food crops, and agricultural production is basically self-sufficient (CUI & ZHANG, 2014). In particular, the main grain producing areas supported by the national ACD are emphasized in the "National Agricultural Comprehensive Development Funds and Project Management Measures." Ensure the country's food security and ecological construction, so that the main grain producing areas can still promote AEE when the proportion of government funds exceeds 62.80%. The optimal share of government funds invested in the main sales areas and the balance areas is 64.07% and 67.36% respectively, but the provinces within these two regions have exceeded the reasonable range.

From the estimated coefficients of other influencing variables, the overall estimated coefficients of the whole country are consistent with the sign and significance level of the variables in Table 3, which can reflect the robustness of the baseline model. Compared with the country in different functional areas, the coefficient signs of most variables and the degree of their influence are more consistent, but there are still differences in individual variables. Specifically, the estimated coefficient of MCI in the main grain producing areas is positive, but the significance test fails, that is, the positive impact of the multiple cropping index on AEE is not significant. The estimated coefficient of URBAN is positive and has passed the 5% significance level test, which is consistent with the national level. The result indicateds that the development of urbanization in the main grain production areas can improve the AEE due to the improvement of agricultural production infrastructure and the development of agricultural industrialization. The impact of CPS in the main grain sales areas is negative like other areas and passed the significant test, because the main sales areas are dominated by cash crops. According to the previous analysis, the expansion of economic crop planting areas will lead to the increase of fertilizer input and the increase of non-point source pollution. These factors are not conducive to the promotion of AEE. The PDIRR and MII in the grain balance areas have the same influence as the country and other functional areas, but these two variables have not passed the significant test. That is, the positive impact of the increase in farmers' per capita income and the negative impact of the intensity of agricultural machinery input are not significant. The reason here may be that the grain production in the balance areas is basically self-sufficient, and the level of agricultural infrastructure and mechanization is still relatively backward.

Spatial effect analysis

The spatial spillover effect of governmental capital investment in neighboring regions is generated in the region, but the spillover effect is relatively weak. The coefficients of investment scale are all significantly negative, which is more consistent with the previous analysis results. From its lag term coefficient, the coefficient of firest lag is insignificantly negative, but the coefficient of second lag is positive, it did not pass the significance level, but it can reflect that the scale of capital investment has a positive effect on AEE with a time lag effect greater than two periods. The previous analysis shows that there has been a significant positive effect since the second lag, which means that the addition of a spatial perspective has prolonged the time lag effect of capital investment on the AEE. The reason may be that local governments are competing for central agricultural development funds, and their own financial resources have strengthened the spatial competition of investment scale between regions.

From the regression results of investment structure, it also confirmed that the investment structure of ACD and AEE present an inverted N-curve relationship. Compared with the previous analysis results, the second turning point has moved forward from 2012 to 2011. After considering the spatial perspective, the frequent flow of spatial facts and the competition of capital investment among regions have accelerated the time when the relationship between investment structure and AEE has been transformed. That is, when the proportion of government investment reaches 72.97%, it is the optimal capital structure.

The enlightenment of this study is that the investment of ACD funds has a significant effect on improving agricultural production conditions and promoting agricultural economic growth, but the use of fund is inefficient and there is a time lag in the impact on AEE. It is not only necessary to continue to increase capital investment in the agricultural sector, but also to ensure the scale of capital investment in ACD. It should be able to match the local agricultural production conditions, reduce current use redundancy, and improve the efficiency of capital use. An effective supervision mechanism can be introduced to ensure that the use of funds for ACD is implemented, and the assessment mechanism for the use of local funds can be improved to clarify the flow of funds. At the same time, there is a reasonable range for the structure of capital investment in ACD, but the current proportion of fiscal capital investment in most provinces has exceeded the upper limit of the reasonable range. So the allocation of the investment structure of ACD needs to be further rationally optimized, and the introduction of capital from civil society should be increased to enhance the enthusiasm of governments at all levels, rural collectives and farmers to participate in ACD. What needs attention is that government funding support for ACD should give more prominence to environmental protection, focusing on agricultural pollution prevention, comprehensive utilization of waste, straw organic fertilizer conversion, development of circular agriculture and other governance projects to transform the mode and path of ACD. In addition, the spatial spillover effect has led to the existence of competition and cooperation between neighboring regions, and a complete cooperative mechanism for ACD and agricultural ecological protection must be established between regions. At the same time, according to the resource endowment and production conditions of the region, the proportion of fiscal expenditures between regions can be adjusted in a timely manner. According to local conditions, ensuring ACD in different regions can improve AEE and realize the sustainable development of the agricultural economy.

CONCLUSION

ACD aims to promote agricultural sustainable development. Based on provincial panel data and econometric models, this paper explores whether ACD improved AEE by measuring AEE in terms of investment scale and investment structure, respectively. The paper further seeks for a reasonable proportion of government funds invested in ACD and the spatial spillover effect of the scale and structure of investment in ACD. The main conclusions of this study are as follows: the investment scale in ACD has a negative impact on AEE in the current period. This is mainly due to unreasonable allocation of funds, lack of efficiency in the funds use, and the existence of redundancy of funds input, which leads to a time lag effect in the process from the inputting funds to the improvement of agricultural production capacity and generation of benefits, and this time lag period is longer in the spatial perspective. Further, using the proportion of governmental funds input as the proxy variable for the investment structure of ACD, and the relationship between the investment structure of ACD and AEE displays a significant three-dimensional “inverted N” curve relationship. The reasonable range of governmental funds input in ACD for AEE is (50.91%, 76.71%), and the optimal funding structure is when the proportion of governmental funds input reaches 76.71%. The impact of the investment structure of ACD on AEE in different functional grain areas presents differentiation, and the optimal governmental funds input shares in the main grain sales areas and the grain balance areas are 64.07% and 67.36%, respectively, but the provinces within them have exceeded the threshold value, while the optimal governmental funds input share in the main grain producing areas is 62.80%.

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DATA AVAILABILITY STATEMENT

The data of the variables involved in the article are from the “China Rural Statistical Yearbook”, “China Agricultural Statistics”, “China Financial Yearbook”, “China agricultural comprehensive development Yearbook” and the National Bureau of Statistics data website. <http://data.stats.gov.cn/easyquery.htm?cn=E0103>.

DECLARATION OF CONFLICTS OF INTEREST

The authors declare no conflict of interest.

AUTHORS’ CONTRIBUTIONS

Conceptualization: TYZ, MYH and LLW. Data acquisition: TYZ, MYH and LQC. Design of methodology and data analysis: TYZ and MYH. TYZ and MYH prepared the draft of the manuscript. All authors critically revised the manuscript and approved of the final version.

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