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Can farmers' combined-tillage promote the agricultural production efficiency? - Evidence from land fragmentation

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ABSTRACT: With the gradual transfer of an enormous young and middle age labor force from agricultural field to non-agricultural sectors, the negative role of land fragmentation (LF), which is related to food security, is increasingly reflecting in the process of agricultural modernization. Meanwhile, the positive roles of farmers' combined-tillage in production are gradually emerging. Based on the above background, this study explained the relationship among farmers' combined-tillage, LF and agricultural production efficiency (APE). The study used survey date and the SFA-QR model to empirically investigate the effects of LF and farmers' combined-tillage on APE. Furthermore, this article analyzed the moderating effect of farmers' combined-tillage on the relationship between LF and APE. The results demonstrated that: (1) Farmers combined-tillage improves the APE significantly, especially on low and medium efficiency households; (2) LF has a negative impact on APE, especially on low and medium efficiency households; (3) Combined-tillage could alleviate the adverse effects of LF on APE. In this regard, the paper also proposed some suggestions to face the adverse effects of LF and promote farmers' combined-tillage in production.
Key words: land fragmentation, agricultural production efficiency, combined-tillage, agriculture production.

O plantio combinado dos agricultores pode promover a eficiência da produção agrícola? - Evidência da fragmentação da terra

RESUMO: Com a transferência gradual de enorme força de trabalho jovem e de meia idade do campo agrícola para os setores não agrícolas, o papel negativo da fragmentação da terra (LF), relacionada à segurança alimentar, está cada vez mais refletido no processo de modernização agrícola. Enquanto isso, os papéis positivos da lavoura combinada dos agricultores na produção estão surgindo gradualmente. Com base no histórico acima, o objetivo deste estudo é explicar a relação entre o plantio direto dos agricultores, LF e eficiência da produção agrícola (APE). O estudo usou dados do levantamento e o modelo SFA-QR para investigar empiricamente os efeitos da FL e do plantio direto dos agricultores sobre o APE. Além disso, este artigo analisou o efeito moderador do plantio combinado dos agricultores na relação entre LF e APE. Os resultados demonstram que: (1) A lavoura combinada dos agricultores melhora significativamente o APE, especialmente em domicílios de baixa e média eficiência; (2) LF tem um impacto negativo na APE, especialmente em domicílios de baixa e média eficiência; (3) A lavoura combinada pode aliviar os efeitos adversos do LF no APE. Nesse sentido, o trabalho também propõe algumas sugestões para enfrentar os efeitos adversos da FL e promover o plantio combinado dos agricultores na produção.
Palavras-chave: fragmentação de terras, eficiência da produção agrícola, cultivo combinado, produção agrícola.

INTRODUCTION

Land fragmentation (LF) is a universal trait of all agricultural systems that affect farmland productivity and rural development (ZHANG & CHEN, 2021), LF also relates to food security. Since the reform and opening-up, China has gradually built a dual management system, which is a combination of both centralization and decentralization based on households contracting (WANG et al., 2021). Taking advantages of this system, China agriculture has made great success that attracts worldwide attention in the past 20 years. However, this method of distribution according to quality and distance of the plot has led to severe fragmentation of agricultural land (LU et al., 2019). Agricultural arable land from LF to large-scale management is regarded as an essential transition path. Meanwhile, agrarian cooperation management is effective to promote the efficiency of factor allocation, pushing forward technological

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innovation and improving the accumulation as well as the development capacity of Agriculture. Combined-tillage has been explored by Chinese farmers in recent years, which not only retain the family management advantages of small farmers but also realize the agricultural scale management without changing or transferring the contracted management right. However, a series of principal problems occurred. First, does LF under current background harm the APE? Second, are farmers with combined-tillage able to reduce these unfavorable effects mentioned above and promote the APE?

For the first problem, there is some research showing that LF would increase both labor forces input and agricultural material loss (CIAIAN et al., 2018), which retards the progress of farming mechanization and finally leads to a growth in production cost. LF also impose a significant adverse effect on food output, especially on the large-scale economy of food production. This decreases production efficiency (VELJANOSKA, 2018), and brings adverse effects on both agricultural management and food security. Thus, most of policies aim to solve the LF problem through land arrangement, agriculture cooperation, voluntary exchange of land, and other methods. Some scholars argued that LF is a selective decision made by the farmers who have balanced risk management, considered the bottleneck constraint of the labor force, and met the demand of crop diversification (KNIPPENBERG et al., 2018). Hence, the block operation is helpful for farmers to manage land, reduce risks in food production and market (QIU et al., 2020), and even improve the farming productivity. Other scholars hold a U-shaped relationship between LF and APE instead of simple linear relation (LOOGA et al., 2018). There are no general and agreed conclusions related to the relationship between LF and APE.

For the second problem, agricultural cooperation plays important role among the elements of sustainable development of agricultural production (LIPATOVA et al., 2021), especially in the process of agricultural modernization. Collaboration could improve human resource and social capital, it is also practical in promoting the degree of agrarian management systematization and saving the costs of transactions (LIU et al., 2018). Although, there is no literature to demonstrate the relationship between the farmers' combined-tillage in production and LF, some researchers state that collaborative management is conducive to unify the scattered lands (ZHANG & PAUDEL, 2021). Meanwhile, the small households who participate in collective actions can make individuals more vigorous to help each other, spread new techniques extensively in the community, and induce the learning effect (BIKKINA et al., 2017). All of these laid the foundation for the further research of farmers combined-tillage and LF, especially for exploring whether farmers combined-tillage affect the relation between LF and APE.

Conclusively, the existing research will be broadened and deepened in the following aspects: First, we have verified the adverse effect of LF on APE under the current background. Second, we have defined the concept and constructed the measurement system of combined-tillage, and analyzed the impact of farmers' combined-tillage on APE with the SFA-QR model. Last, we examined the moderate effect of combined-tillage on the relation between LF and APE. The aim of this paper are to offer a fresh perspective for further researches relevant to LF and farming cooperation patterns, it also provides new experimental enlightenment for the development of farmers' combined-tillage in production.

Literature review and theory construction

Analysis of the Relationship between LF and APE

The concept of LF is applied extensively, but the definition is difficult to measure and compare (NTIHINYURWA et al., 2019). Furthermore, LF has ambiguous properties, which is influenced by composite factors including policy, economy, geographical features (GOMES et al., 2019). Synthesized by the different opinions, scholars agree three kinds of implications about LF: (i) various land plots are shaped by natural characteristics of topography and geomorphology (ii) fragmentation in property rights is caused by the segmentation of continuous farmland between different households. (iii) LF is caused by diversified planting (TUNG, 2012). Because all subjects in our study are wheat growers, this paper mainly focuses on the fragmentation related to property rights. With the rapid development of the market, and the improvement of agricultural production conditions, the negative role of LF in the process of agricultural modernization is increasingly reflected (WANG et al., 2020). First and foremost, LF makes farmers move back and forth between different land plots, which result in a higher cost of farming management (KAWASAKI, 2010). Simultaneously, production cost is increased because transportation loss of production is intensified (LATRUFFE & PIET, 2014). Moreover, the fragmentation of property rights causes significant negotiation expenditure and restrains the households' behaviors of voluntary investment. Second, as for the adoption of new technology, LF is likely to increase the difficulty of machinery usage and unified farming (WANG et al., 2020), and raise the threshold of technology adoption. Last, in terms of agricultural output, LF reduces both crop yield and farming productivity (ASIAMA et al., 2019), then affect food security. Hence, LF is unfavorable for the effective concentration of land, and it is difficult to achieve Pareto Optimality of resource allocation. LF also make scale merit impossible. Therefore, this paper illustrates the first hypothesis as follows:

Hypothesis 1: LF plays a negative role on the APE. That means, the higher the degree of LF, the lower the APE is.

Analysis of the relationships among LF, APE and farmers' combined-tillage in production

A large quantity of theoretical and empirical studies about the solutions of LF spread all around the world (NILSSON, 2019). In general, most prevailing solutions can be summed up into two methods: market approach and administration mechanism. The former, whose patterns mainly include the definition of property rights and the transactions in the markets (LI et al., 2019), is referred to rearrange decentralized land through the "invisible hand." Many scholars hold that theory as long as the cost of LF exceeds the revenue, thus the solutions of centralized land utilization to LF will be found and put into effect naturally. The latter, administration mechanism, is mainly defined as the centralized utilization of fragmental land achieved by administrative means (JIN et al., 2016). Generally speaking, compulsory participation are exist in the implementation of the administration mechanism, specifically in land leveling and the redistribution of land plots.

However, because of the particularity of fragmental land, not only does the market mechanism often "fail" in the distribution of fragmental land, but government is also unable to play a decisive role in solving the problems of LF. As a result, farmers in different areas will explore new solution models of LF actively. Consequently, combined-tillage in production emerges naturally. Combined-tillage means that fragmented land is centralized without changing the allocation of agricultural land elements or the contracted management right of farmers, and unified wheat varieties and planting links. This method achieves unified guidance in agricultural production and farming. This method also pushes the standardization of production and intensive management. It also reduces production cost while improving the efficiency in resource utilization, change peasant households' vulnerable status, keep the economic surplus in agriculture, ameliorate agriculture self-accumulation, and enhance the APE. Thus, the second hypothesis is proposed as follows:

Hypothesis 2: Farmers' combined-tillage can improve the APE if all other conditions are exogenously given and invariant.

Besides, the combined-tillage achieves centralized management of multiple-block-joint land while keeping the current land contracting relationship unchanged. Combined-tillage overcome both the malfunction of market mechanism and the power abuse of administration approach while effectively averting the households' worries about property disputes arising from cooperation. Negotiation costs and the disadvantage of property division are reduced through combined-tillage. Combined-tillage also concentrates large-scale management and production, improves the efficiency of land resource allocation, relieves the wastage of agriculture production materials caused by LF. It is beneficial for the mechanization of farming, alleviates the mechanical operation difficulties, and it also play a positive role in improving grain output. Thereby, combined-tillage plays a vital role in moderating the relationship between LF and APE. Hence, this paper put forward the third hypothesis as follows:

Hypothesis 3: Combined-tillage would play positive roles on the relationship between LF and APE.

MATERIALS AND METHODS

Data sources

From July to August 2020, we collected survey data in Henan and Shanxi Province. The topic of the survey is "cooperative behaviors in production of wheat growers." In most parts of Henan province and the south area of Shanxi province, social service organization and entrusted land management have developed obviously, which established a good foundation for the study of farmers' combined-tillage in production. The survey adopted a double-sampling approach to determine the investigation sites and respondents.

The first sampling was conducted by non-probabilistic method to determine the specific locations. We select Anyang city of Henan province and Linfen city of Shanxi province as survey areas to represent winter wheat main producing regions and balance areas in this session. Anyang city has jurisdiction over Hua County whose wheat yield is top ranked in China. Wheat yields of other counties in the Anyang region contain entirely upstream, midstream, and downstream of the province, representing the wheat production in Henan sufficiently. Linfen city, as the principal wheat-producing area of traditional mining province, could represent wheat production in the no-dominant areas. From above information, the combined-tillage of wheat growers, which include all production levels can be comprehensively explored in these two regions. Therefore, our survey areas are suitable for the research. To ensure that the survey covers villages and towns contain different economic levels, we choose all the counties in Anyang and all counties except non-grain producing areas in Linfen. There are 16 sample counties in total.

The second sampling was conducted by stratified random method to determine the specific objects in each sampled county. This paper followed the principle that 1-2 sample-towns were randomly selected from each county, 2-3 villages were randomly selected from each town, and 15-20 sample farmers (production decision-makers) were randomly selected from each sample village for one-to-one interviews. The questionnaires mainly include the situation of LF, combined-tillage and the characteristics of households which contain the households' age, education and other related information, as well as the primary family information which comprises labor force and land quality, etc.

Totally, we collected 870 questionnaires from 16 counties, 25 towns, and 53 villages. Exclude from the incomplete and the distorted ones, 857 valid questionnaires were obtained as our final sample. Here are some data from our investigation with the efficient rate of 98.5%. The proportions of combined-tillage are 34.42%; The average age of the households was 54.39, and the education level is mainly junior high school or below; The land area per households is 6.36 mu (approximate 0.424hm2), which is equivalent to official data in 2019; The number of migrant workers occupied more than 50% of labors.

Variable election

Agricultural production efficiency(APE)

Based on various research, this paper uses stochastic frontier analysis (SFA), and regards each household as a decision-making unit. We set the seed cost, fertilizer, mechanism, labor, and land area as input index, while put the wheat production value as output variable, then we use the data we collected to measure the comprehensive efficiency of input and output.

Land ragmentation(LF)

Due to the multidimensional and complex nature of LF, there is not a recognized international standard or indicators to measure the LF. This paper intends to select the Simpson-index to depict LF, whose value is the difference between the square sum of plots area divided by the square sum of agricultural land area and 1. The larger the Simpson-index is, the higher degree of LF could be.

Combined-tillage

Combined-tillage means households cooperate in one or more links of farming, planting, management, and harvesting. The specific item setting, assignment, and descriptive statistics are shown in table 1.

Control variable: individual characteristics and familye Endowments

According to behavioral economics and existing research, individual characteristics and family endowments have an essential impact on households' behaviors. They are important control variables in existing studies (FENG & HEERINK, 2008). In individual characteristics, we choose households' age and educational level as specific indicators and then select labor quantity and land quality to represent family endowments. Besides, this paper also includes regional dummy variables. The variable meanings and descriptive statistics are shown in table 1.

Substitution variable in robustness test: J-index.

This paper uses J-index as a substitution variable to describe LF in the robustness test. Opposite to Simpson index, J-index is the ratio of the sum of the square root of the total farm area to the square root of the plot area, and the degree of LF decrease with the increase of the J-index.

Model uilding

SFA model

The mainstream efficiency evaluation methods include parameter models (represented by SFA) and non-parameter models (represented by DEA). Compared with DEA, SFA could take the influence of random factors into account and reflect the functional relationship between the input combination and maximum output under specific technical conditions and a given combination of production factors. We can obtain the comprehensive efficiency of households by comparing the gap between the actual output and the ideal optimal output. The basic model of SFA is set as follows:

$$y_i = f(x_i, \beta) \exp(v_i - u_i) \quad (1)$$

In the above equation, y_i means agricultural outputs of the i-th household. x_i means input factors which include seed and fertilize, land and labor, etc. v_i

Table 1 - Variable definition and descriptive statistics.

	Name of variables	Variable assignment	Mean value	Std Dev
Dependent variable	Agricultural Production Efficiency	SFA calculation results	0.406	0.006
Major independent variable	Land Fragmentation	Simpson index	0.509	0.009
Moderate variables	Combined-tillage	Combined-tillage＝1, Others＝0	0.344	0.016
Control variables	Age	Years(of age)	54.393	0.370
	Education	Below primary school level=1, primary school level＝2, junior high school level＝3, high school level＝4, collage or above＝5	2.711	0.031
	Labor quantity	Number of labor	2.455	0.038
	land-quality assessment	%	3.781	0.038
	Areas	Main wheat- producing area＝1, others＝0	0.573	0.017
Substitution variable	LF	J-index	0.625	0.007

means stochastic error, indicating the uncontrollable influence factors of sample unit in production. u_i is the distance between the sample output and the ideal output value, which is the technical inefficiency term. Supposing that the noise of uncontrollable factors follows a normal distribution, we can define the efficiency of input and output of households as:

$$TEi = \exp(-u_i) \quad (2)$$

The closer TE_i value to 1, the higher efficiency level; the closer TE_i value to 0, the greater efficiency loss.

Quantile regression model

Quantile regression (QR), which is first proposed by KOENKER & BASSETT (1978), can better reflect the whole picture of the conditional distribution compared with the ordinary least squares method. QR regresses the independent variables to the dependent variables in different quantiles and finally obtains the effect of the independent variable on the entire conditional distribution. Besides, Quantile regression uses a weighted average of absolute residual value as an objective function of minimization, making the results are not easily affected by outliers. QR model is more relaxed on the distribution assumption of the error term, and it is more robust when applied to non-normal distribution data. According to the researches (ZHANG et al., 2020), we adopt the quantiles of 0.1,0.25,0.5,0.75,0.9 to analyze the data. The specific equation is as follows:

$$y_q(x_i) = x_i \beta_q \quad (3)$$

In the above equation, $y_q(x_i)$ is a linear function of x_i, represents the APE. x_i denotes the LF, combined-tillage, joint-households-management, and control variables that may affect APE. β_q is the regression coefficient of Q-quantile.

Group regression model

According to Cohen et al. (2003), if the relationship between dependent variable Y and independent variable X changes with the third variable Z, we called the variable Z a moderate variable. When X is a continuous variable and Z is a category variable, we can use group regression to test the moderating effect of variable Z on the specific path relationship. By comparing the difference of X regression coefficient in different groups, we gauge variable Z has a significant moderating effect when the difference is significant. Since the core independent variable is continuous and the moderator is category variable, we test moderating effect by grouping regression analysis.

RESULTS

The Impact of LF and farmers' combined-tillage on APE

The empirical results of the SFA-QR model are presented in table 2. It shows the impact of LF on the APE in different degrees. The findings indicate that the negative impact of LF on APE shows a fluctuating trend of rising first and then falling with the change of quantile level of APE (quantile from 10%-25%-50%-75%-90%). Furthermore, the results mean that the negative effect of LF is more significant on low-efficiency peasant households than high-efficiency one. In a word, LF has a negative effect on APE, and the deepening of LF will restrict the improvement of APE. The possible explanation is that

Table 2 - Results of the effect of Land Fragmentation on Agricultural Production Efficiency.

	OLS	Q10	Q25	Q50	Q75	Q90
Simpson-index	-0.119*** (0.016)	-0.106*** (0.031)	-0.111*** (0.027)	-0.135*** (0.026)	-0.065*** (0.016)	-0.066*** (0.017)
Combined-tillage	0.071*** (0.010)	0.093*** (0.021)	0.066*** (0.025)	0.079*** (0.010)	0.038*** (0.012)	0.021** (0.007)
Age	-0.001*** (0.001)	-0.002*** (0.001)	-0.002*** (0.001)	-0.002*** (0.001)	-0.001* (0.001)	-0.001** (0.001)
Education	0.026*** (0.004)	0.038*** (0.004)	0.043*** (0.005)	0.029*** (0.005)	0.007 (0.005)	0.002 (0.003)
Number of labor force	0.042* (0.025)	0.104*** (0.035)	0.031 (0.040)	0.025 (0.033)	0.004 (0.017)	-0.007 (0.012)
Land quality assessment	0.033* (0.017)	0.002 (0.020)	0.003 (0.003)	0.060** (0.030)	0.067*** (0.012)	0.021 (0.017)
Area	0.065*** (0.008)	0.094*** (0.017)	0.067*** (0.014)	0.042*** (0.010)	0.071*** (0.013)	0.065*** (0.008)
Cons	-0.061** (0.029)	-0.252*** (0.045)	-0.125*** (0.033)	-0.015* (0.045)	0.012 (0.021)	0.110*** (0.017)

Notes: (1) *、 ** and *** indicate significance at 10%, 5%, and 1% levels, respectively; (2) The standard errors are reported in parentheses.

mechanical substitution has become a trend with the development of agricultural modernization. But when the LF reaches a certain degree, it would cause small plots adverse to the unified operation of machinery and rise unreasonable allocation of production factors, then reduce agricultural output. Besides, the aggravation of LF would increase the loss of means of production, adds input costs, and makes households face high cost of property rights negotiation, then restrains the investment of peasants, finally reduces the APE. Therefore hypothesis 1 is proved.

The findings in table 2 also indicate that combined-tillage has promoted the APE significantly. With the increase of the behaviors about combined-tillage, the APE has made significant progress. More specifically, with the change of quantile level of production efficiency (quantile from 10%-25%-50%-75%-90%), the promoting effect of combined-tillage on APE shows a fluctuating downward trend. That prove the combined-tillage is beneficial to the improvement of the efficiency of low productivity households. The possible explanation is that households with low or medium production efficiency are more likely to be restricted by objective conditions such as resource endowments and are more necessary to carry out agricultural transformation in the context of urbanization. Moreover, the improvement of cooperative agricultural management can optimize the objective condition of agriculture production and management. It also realizes the centralized integration of production factors, improve the efficiency of resource allocation and utilization, and provide diversified services and unified guidance in the supply of agricultural materials, operation, and management etc. Combined-tillage can also reduce production input costs while saving transaction costs, enhances the effect of economies of scale, and improves the production capacity of agricultural. Especially breakthrough the endowment constraints of low and medium efficiency households, improves their productivity, and realizes the smooth docking between small households and large market. Thus hypothesis 2 is proved.

Moderating effect of farmers' combined-tillage on the relationship between LF and APE

To analyze the moderate effect of combined-tillage on the relationship between LF and APE, the respondents are divided into two groups: combined-tillage and non-combined-tillage. Then, we conducted QR-regression based on each sub-sample. Results are shown in table 3. According to this, we found that in the group of combined-tillage, the coefficient on LF is insignificant on APE. While in the non-combined-tillage group, coefficient on LF has a significant negative impact on APE. Next, we used Chow-test to check the difference between the coefficient of the LF in the two regressions. The finding suggested a significant difference in the coefficient of LF between the two groups, which means combined-tillage

Table 3 - Grouped regression results of the moderate effect of combined-tillage.

		Q10	Q25	Q50	Q75	Q90
Combined-tillage	S-index	-0.046 (0.042)	-0.071 (0.045)	-0.001 (0.042)	-0.020 (0.026)	-0.036 (0.022)
Non-combined-tillage	S-index	-0.151*** (0.032)	-0.169*** (0.023)	-0.175*** (0.030)	-0.088*** (0.028)	-0.064*** (0.016)

Notes: (1) The regression results include all variables in table 3 except the combined-tillage but not reported to save space; (2) QR model is used to estimate the data in the table, and only the estimation results of Simpson-index (degree of LF) affecting APE are reported here. (3) *、 ** and *** indicate significance at 10%, 5%, and 1% levels, respectively, and the standard errors are reported in parentheses.

has a significant moderate effect on the relationship between LF and APE. The possible explanation is that combined-tillage can centralize households' land to realize continuous planting without changing the land property rights system of China. Combined-tillage plays a significant role in reducing the waste of production materials by unifying planting, farming, and management. Hence farmers' combined-tillage is beneficial to use advanced machinery, increase the economies of scale and wheat yield, thereby reducing the adverse effects caused by LF and improving the APE. Hypothesis 3 is confirmed.

Robust test

Replacement of the core variable

To verify the robustness of the above results, we use J-index to characterize LF. J-index was calculated by the ratio of the sum of the square root of the total farm area to the square root of the plot area, and the degree of LF decreased with the increase of J-index opposite to Simpson-index. Results are shown in table 4. J-index is positively correlated with APE, which means the smaller the LF, the higher the APE. With the increase of quantile (from 10%-25%-50%-75%-90%), the impact of the J-index on APE shows a trend of amplifying first and then decreasing. The finding have no significant change compared with the above results, illustrating that the estimation results of the relationship between LF and APE are robust. Combined-tillage still affects APE positively after replacing Simpson-index. The robust results showed the relationship between farmers' combined-tillage in production and APE is relatively stable.

Model eplacement

Because the production efficiency value is between 0 and 1, the distribution of dependent variables both partially continuous and partially discrete. We also use another model as a second robustness check, Tobit-regression, to solve the truncation problem of dependent variables and avoid sample selection errors. The Tobit model is as follows:

$$Y_i^* = \beta_0 + \beta_i F_i + \beta_1 M_{1i} + \beta_2 FM_{1i} + u_i,\ i = 1,2,\dots, n \qquad (4)$$

In the above equation, F_i means LF. M_{1i} is the farmers' combined-tillage in production. β_i means the coefficient to be estimated. u_i is the random interference term. Y_i^* is a latent variable. Y_i means the productivity of the i-th household. And Y_i satisfy the following formula:

$$Y_i = \begin{cases} Y_i^*, if & Y_i^* > 0 \\ 0, if & Y_i^* \le 0 \end{cases} \qquad (5)$$

Table 5 presents the robust test results with Tobit regression. The statistical value of LR in each group is very significant (P＝0.000), which means the joint significance of all coefficients (except the constant term) of the whole equation is obvious. Results showed that the impact of LF on APE is not significant among the group of combined-tillage. The chow test indicated that there is a significant difference in the coefficient of LF between the combined-tillage group and non-combined-tillage. Therefore, the adverse effects of LF on APE can be alleviated by combined-tillage. In contrast to previous results, the non-existence of significant change means the moderating effect is robust.

Conclusions and policy implications

CONCLUSION

With the rapid development of the market and the gradual transfer of young and middle-aged labor force from agricultural field to non-agricultural sectors, as well as the rapid improvement of agricultural production conditions, the negative role of LF in the process of agricultural modernization is

Table 4 - Robust analysis of the impact of Land Fragmentation and farmers' cooperative behaviors in production on Agricultural Production Efficiency.

	OLS	Q10	Q25	Q50	Q75	Q90
J-index	0.147*** (0.021)	0.125*** (0.041)	0.114*** (0.030)	0.179*** (0.024)	0.101*** (0.030)	0.095*** (0.023)
Combined-tillage	0.068*** (0.010)	0.095*** (0.019)	0.065*** (0.020)	0.069*** (0.012)	0.038** (0.016)	0.018** (0.007)
Joint-households-management	0.066*** (0.010)	0.106*** (0.019)	0.066*** (0.018)	0.051*** (0.011)	0.030* (0.016)	0.014** (0.007)
Control variables	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Cons	-0.215*** (0.030)	-0.397 (0.051)	-0.221*** (0.051)	-0.199*** (0.042)	-0.094*** (0.033)	0.016 (0.021)

Notes: (1) The regression results include all control variables but are not reported to save space; (2) QR model is used to estimate the results in the table. (3) *、 ** and *** indicate significance at 10%, 5%, and 1% levels, respectively, and the standard errors are reported in parentheses.

increasingly reflecting. In contrast, the positive role of famers' combined-tillage in production is gradually appear. Based on this background, this paper uses the field survey data of the Huang-Huai wheat area in winter 2020, and applies the SFA-QR model and the moderate model to empirically investigate the relationship among LF, farmers combined-tillage, and APE. The conclusions are as follows:

Firstly, LF has a significant negative effect on APE, and no matter in which level of production efficiency, the aggravation of LF would inhibit the improvement of APE. However, with the change of quantile level of APE, the negative impact of LF on APE shows a fluctuating trend of rising first and then falling. That means the negative impact of LF on low-efficiency households is greater than that on high efficiency ones.

Secondly, farmers' combined-tillage in production promotes the APE significantly. Despite the change of quantile level of APE, the facilitation caused by combined-tillage shows the trend of fluctuant reduction and gradually decreasing. The combined-tillage promote APE at different quantile levels, which means that the more the households adopt combined-tillage, the more improvement and amelioration of APE could be.

Lastly, combined-tillage could alleviate the detrimental effect of LF on APE. One or more links in the combined-tillage such as farming, planting, management, and harvesting could undertake contiguous cultivation of large regional scale. It also alleviate issues such as the waste of production material, diseconomies of scale, and difficulties in mechanical implementation caused by LF, then improve the APE finally.

Policy Implications

Based on the above research conclusion, we proposed some suggestions to promote the occurrence of farmers' cooperative behaviors in

Table 5 - Robustness test of the moderate effect of famers' cooperative behaviors in production.

	Combined-tillage	Non-combined-tillage
Simpson-index	-0.031 (0.029)	-0.169*** (0.020)
Control variables	introduced	introduced
Number of samples	295	562
Prob>chi2	0.000	0.000

Notes: (1) The regression results include all control variables but are not reported to save space; (2) Tobit model is used to estimate the results, and only the estimation results of S-index(degree of Land Fragmentation) affecting Agricultural Production Efficiency are reported here in the table.(3) *、 ** and *** indicate significance at 10%, 5%, and 1% levels, respectively, and the standard errors are reported in parentheses.

production, reduce the adverse effects of LF and avoid food security issues:

Firstly, it is necessary to fully appreciate that LF will remain unchanged for a long time, and the penalty of LF in reducing crop yield, hindering mechanical substitution, would be present continuously. Therefore, it is appropriate to promote the consolidation of rural land and the construction of high-standard farmland, then fully activate the organic combination of market, government, and self-administrative system. Both the government and individuals are encouraged to take suitable ways to realize the economic effect of land contiguous to counter the LF caused by different reasons, then reduce the disadvantage of LF in the actual land management process.

Secondly; although, the farmers' combined-tillage in production are in an embryonic state and have a relatively narrow coverage, its production advantages significantly enhancing the APE under the background of a high degree of LF. Therefore, it is necessary to encourage peasant households to participate more active in agricultural production cooperation. The government need to improve the internal governance mechanism and external supervision measures corresponding to combined-tillage.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest for this article. The founding sponsors had no role in the design of the study, in the collection, analyses, or interpretation of data, in the writing of the manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

Conceptualization, Y.W.; Methodology, Y.W. and F.Y.; Soft-ware, Y.W. and Y.G.; Validation, Y.W., and Q.M.; Formal analysis, Y.W. and M.L.; Investigation, Y.W., M.L. and Y.G.; Data curation, Y.G.; Writing—original draft preparation, Y.W.; Writing—review and editing, Y.W., F.Y. and Y.G.; Visualization, Y.G. and Y.W.; Supervision, Q.M.; Project administration, Q.M. and Y.W.; Funding acquisition, Q.M. All authors have read and agreed to the published version of the manuscript.

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