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Assessing the Impacts of Land Consolidation on Agricultural Technical Efficiency of Producers: A Survey from Jiangsu Province, China

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Abstract: Since the year 2000, China has implemented large-scale land consolidation, which was used to reduce land fragmentation, enhance grain yield capability, facilitate land tenure transfer, and promote agricultural operational scale. However, the impacts of land consolidation on agricultural technical efficiency of producers in practice is not yet clear. A field survey was executed at two points of time during July 2010 and July 2016. A total of 900 producers were chosen from 30 land consolidation projects at random in the Jiangsu Province. The agricultural technical efficiency caused by land consolidation was calculated by using a stochastic frontier analysis method. The results of a stochastic frontier production function reveal that land tenure transfer, land fragmentation, non-agricultural income, and crop diversity has undergone significant changes after land consolidation. The overall agricultural technical efficiency of producers had also increased considerably and the average technical efficiency was estimated at 0.924 after land consolidation. Land consolidation directly promotes land tenure transfer while indirectly encouraging non-agricultural employment, which could improve agricultural technical efficiency of producers. Non-agricultural income and crop diversity had a significant correlation with agricultural technical efficiency, but land fragmentation after land consolidation does not significantly improve technical efficiency. These conclusions are helpful in understanding the impacts of land consolidation, which enriches the academic literature in related fields and improves the policy of land consolidation in China and other developing countries.

Keywords: land tenure transfer; land fragmentation; crop diversity; stochastic frontier analysis; rural development

1. Introduction

Land consolidation has been extensively employed as a powerful tool for land use management in many countries [1–4]. Land consolidation is a complex project involving land leveling, village renewal, farmland irrigation systems, road networks improving, land tenure transfer, agricultural landscape, and natural resources [5,6]. After land privatization in Eastern Europe and Africa, land consolidation has been implemented extensively to optimize land tenure structure and to reduce land fragmentation [7–9]. Land consolidation was expected to the maintain rural landscape, mitigate the rural population outflow, and vitalize the rural economy in Western Europe, Southern Africa, and Central Asia [4,9–11]. Previous studies were more concerned with the natural process of land

consolidation. For example, land consolidation has an adverse effect on soil properties in the short term [12], increases the efficiency of land and water resource use [13], and changes the agricultural landscape structure [14], which is favorable for rural sustainability [15]. Current studies related to socioeconomic impacts of land consolidation focus on the adjustment of land property rights, the transformation of agricultural production methods, and the transfer of rural labor [5,16–18].

Technical efficiency is a key indicator of agricultural productivity [19–26]. Fleisher and Liu [27] found a significant negative effect regarding the number of plots on yield from a survey of 1200 farm households in Jiangsu Province, China [26]. All other factors being equal, for every 10% increase in the number of plots, the yield declines by 5.7%. Nguyen et al. [28] found significant positive correlations between the average area per plot and the yields of corn, wheat, and rice from a survey of 1200 farm households. Wan and Cheng [19], based on the above data, found that, for a plot increase in each household, crop yields declined by 2.0% to 9.8% [19]. Land fragmentation is estimated to waste about 3.0% to 5.0% of farmland, as well as a significant increase in agricultural cost and a fall in agricultural productivity by 15.3% in China [29]. Tan et al. [30] believed that there is a positive correlation between the increase of farming plots and the technical efficiency of rice producers. Previous studies in other countries have also shown similar results [22,31–33]. However, some scholars hold different views [34–37]. Land fragmentation is considered the result of rational choices made by the farm households in pursuit of income maximization. Land fragmentation is beneficial for increasing crop diversity. Higher crop diversity is helpful to circumvent unexpected natural or market risks, which mitigates fluctuations in output or income [22,28]. Niroula and Thapa [11] and Guvele [38] believed that crop diversity caused by land fragmentation are important for reducing the natural and market risks, especially in agricultural vulnerable areas with labor shortages and frequents natural disasters. Manjunatha et al. [24] and Rahman and Rahman [39] discovered that small farms in South Asia are more effective in resource utilization as compared to large farms.

China has witnessed huge changes in agriculture since the year 2000. According to De Brauw et al. [40], the labor input in terms of working hours per household are reducing rapidly in China, from 3500 h per year in 1991 to only 1400 h per year in 2009. However, the actual wage of the rural laborer has increased by 100% between 1998 and 2007 [41]. Given the instability of non-agricultural employment and agriculture tax exemption in 2004, almost no migrant workers in China voluntarily give up land tenure [42]. In some economically developed regions of China, some small plots were abandoned due to little profit and the failure of mechanized planting. This is consistent with a previous study [20]. When the rural labor supply fails to meet the demand for land fragmentation, human agriculture would be replaced by mechanized planting. In addition, the non-agricultural employment could provide more updated information and capital to other family members, which helps reduce economic risks [43]. A free transfer of land tenure could promote a reasonable flow from inefficient farmers to highly efficient farmers, which would make the marginal output more consistent and increase agricultural efficiency [44–47]. However, some studies seemed to imply that farmland renting did not increase productivity. Instead the productivity decreased because of renting [45,48–51]. China's land consolidation programs started in the year 2000 and were initially intended to compensate for the farmland lost due to urban development, in order to achieve a dynamic balance of farmland area [52]. The Land Consolidation Plan of China (2011–2020) stated explicitly the political mission of constructing 2.67×10^7 ha and 5.34×10^7 ha of high-standard farmland by the end of 2015 and 2020, respectively [53,54]. China has invested over 300 billion CNY into land consolidation for high-standard farmland [54]; however, little is known about the actual impacts of land fragmentation, crop diversity, and land tenure transfer caused by land consolidation on agricultural technical efficiency of producers [18,55–59].

Land consolidation really changed agriculture, the countryside, and farmers in China [6,18,60]. The adjustment of China's national development strategy in Xi's era imposes new demands on the functions of land consolidation, which are to adjust the land use structure (production, living, and ecology) to build spatial patterns of land use compatible with the national development strategy,

and is to serve the aims of ecologically sustainable development. Given huge investments and strong desires of rural revitalization in China, an assessment of the impacts of land consolidation on agricultural technical efficiency of producers is very necessary in China. To our knowledge, there is no research emphasizing the direct impacts of land consolidation on technical efficiency of producers. The aims of this study include performing a quantitative survey of the impact of land consolidation on land fragmentation, land tenure transfer and crop diversity, assessing the actual effects of land fragmentation, land tenure transfer, and crop diversity on agricultural technical efficiency of producers, and providing guidance for policy makers on land consolidation measures to promote agricultural sustainability.

2. Data and Methodology

2.1. The Study Area and Data Collection

2.1.1. The Study Area

The study area is located in the Jiangsu Province, which is an eastern coastal province in China (116°18′–121°57′ E, 30°45′–35°20′ N). The Yangtze River divides the Jiangsu Province into two parts. The southern region has a subtropical oceanic monsoon climate with an average temperature of 16 °C and annual average precipitation of 1350 mm. The northern region has a temperate oceanic monsoon climate with an average temperature of 13 °C and an average annual precipitation of 960 mm. In 2015, the Jiangsu Province had a population of 79.763 million, an urbanization rate of about 66.5%, and a regional GDP of 7,011,638 million CNY [61]. A double cropping system is adopted in the Jiangsu Province. In the southern region, rice–wheat rotation predominates. However, the northern region has a more complex cropping system, which is predominantly the rice–wheat rotation system in the southern tip, the maize–wheat rotation system in the northern tip, and the rice–rape rotation system in the middle region. In the northwest, a soy–wheat rotation method takes up a certain proportion and, in the eastern coastal region, rice–cotton intercropping is more common. The Jiangsu Province is a typical delta plain with plain and water bodies accounting for 90.0% of the total land area. The farmland is divided by river networks. The Jiangsu Province is also one of the most economically developed provinces in China even though the rural–urban gap may be very large.

2.1.2. Data Collection

A total of 953 land consolidation projects were implemented in the Jiangsu Province from 2001 to 2015. The area of land consolidation is 866,104.2 hm^2, which accounts for 18.9% of the total farmland area in the Jiangsu Province. The cumulative investment is 22.76 billion CNY (Figure 1). We were commissioned by the Land Consolidation Center in the Jiangsu Province to assess the outcome of land consolidation. The first field survey was conducted in July 2010 to collect the baseline data before land consolidation. From 2009 to 2010, 30 projects were randomly selected for the survey. Then a second field survey was performed in July 2016 to measure agricultural input–output changes between 2010 and 2016 with more than 30 projects. For each project, 30 farm producers were randomly selected. The investigators conducted a face-to-face interview with the agricultural producers in the field survey and completed a questionnaire form provided by the respondents. The survey covered the following areas: (1) general information on the agricultural producer such as the number of household laborers, age and educational background of the head of the household, the type of crops planted, the area of each crop planted, and the number of plots, (2) information on production such as capital investment in the factors of production (laborers, seeds, fertilizers, and other costs), land rental fees, yield, and sale price of each crop. The data on land tenure allotment and land use maps were obtained from a local village committee and the Department of Land and Resources. A spatial vector database was built using ARCGIS 10.2 software (ESRI, Redlands, CA, USA). The distance of the plots from the

dwellings, Simpson's index (SI), and the percentage of rented land were calculated. After checking and verification, 842 and 858 valid samples were collected in the first and second survey, respectively.
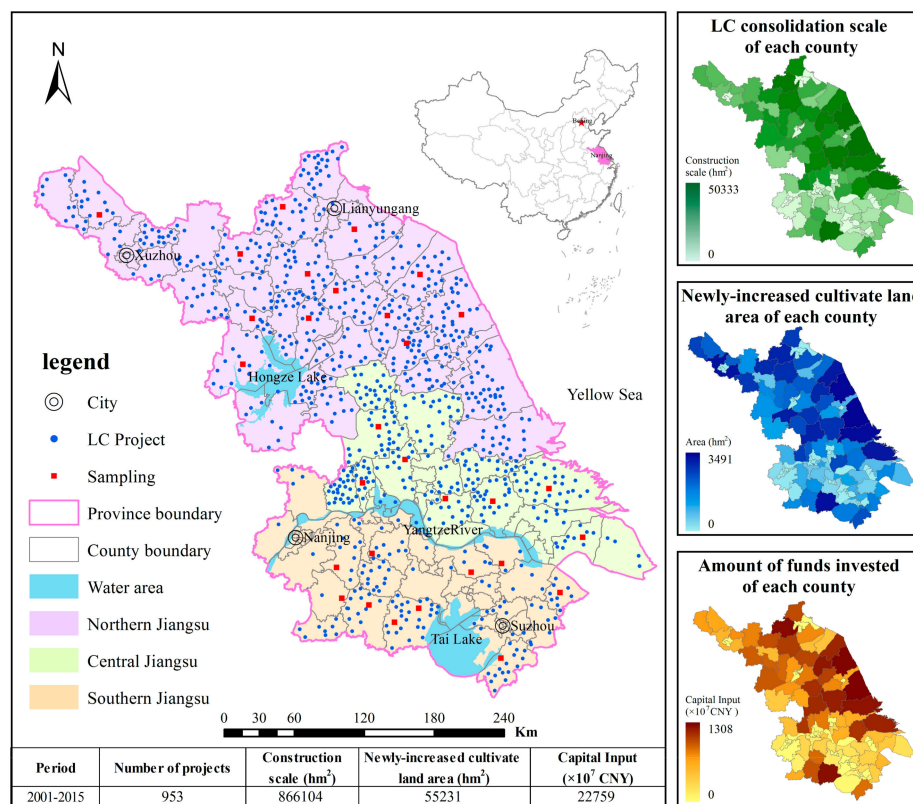

Figure 1. Location of the study area and basic sample data.

2.2. Empirical Models and Variable Selection

2.2.1. Empirical Models

Technical efficiency can be analyzed by using parametric or non-parametric methods. Both methods have their strengths and weaknesses [62–65]. Given the wide scope of factors of production considered and the relatively small sample size, regression analysis using the translog production function may have low efficiency and high uncertainty. Therefore, stochastic frontier production models, which are parametric models, were used to assess the impact of land consolidation on the technical efficiency of agricultural production. To do this, it must be assumed that the production elasticity is a constant and the elasticity of substitution is 1, which imposes a strong limit on the flexibility of the production function. Although the stochastic frontier production function cannot fully represent the actual features of agricultural production, it provides an accurate measurement of technical efficiency [66] regardless of the specific form of the production function [67]. Following the assumptions made by Coelli and Perelman [63] and Battese and Coelli [68], the stochastic frontier production function is expressed below:

$$Y_i = f(X_i; \beta) exp(v_i - u_i), \tag{1}$$

where Y_i is the total output of the *i*-th farm household, *f(●)* is the output on the production possibility frontier that represents the maximum possible output combination under a particular input of factors of production and current technologies, X_i is the input vector of the various factors of production for the *i*-th household, β is the estimated parameter that determines the production function *f*, $v_i - u_i$ is the disturbance term of the models, and v_i is the random error term for the *i*-th household. Assuming

that v_i is independent, it is identically distributed, i.e., $v_i \sim N(0, \sigma_v^2)$. u_i is a non-negative variable representing technical efficiency.

Technical efficiency (TE), i.e., $f(\bullet)$, is the maximum potential ratio of the observed total crop output to the output estimated by the stochastic frontier production function. Its value lies between 0 and 1. Under the assumption made with the stochastic frontier production function, technical efficiency is expressed by the equation below.

$$TE_i = y_i / exp(x_i\beta) = exp(x_i\beta - u_i) / exp(x_i\beta) = exp(-u_i), \tag{2}$$

where TE_i is the technical efficiency of the i-th household and the meaning of the parameter is the same as above. u_i is a set of functions of the factors influencing technical efficiency. It can be used to test the inefficiency in the random variables, i.e., the distance between the plot output and production possibility frontier. It is assumed that u_i is independent of v_i, $u_i \sim N(z_i\delta_i, \sigma_u^2)$. Under the assumptions of the stochastic frontier production function, technical inefficiency is given by Equation (3):

$$u_i = \delta_0 + \sum_{i=1}^{n} \sum_{k=1}^{k} \delta_k z_{ik} + \omega_i, \tag{3}$$

where z_{ik} is the vector of explanatory variables believed to account for technical inefficiency. ω_i is a random error term, which is a random variable obeying the extreme value distribution. δ_k is the estimated parameter that represents the effect of the inefficiency variable. If δ_k is a non-negative variable, it has a positive impact on technical efficiency. If it is negative, it has a negative impact on technical efficiency. n is the sample size.

2.2.2. Model Construction

Using Formula (1), the stochastic frontier profit function to be estimated has the following form:

$$ln(Y_i) = \beta_0 + \sum_{i=1}^{n} \sum_{k=1}^{k} \beta_k \ln(x_{ik}) + v_i - u_i, \tag{4}$$

where dependent variable Y_i is the total output for the i-th agricultural producer and x_{ik} is the input of the various factors of production including labor, fertilizers, seeds and other materials. The cost of each factor of production is first estimated for each crop and then a summation of costs is obtained for the combinations of crops when assuming that the profit function is independent of the impact of the different production factors and other characteristic variables.

According to Equation (2), the estimation model for technical efficiency is shown below:

$$TE_i = \delta_0 + \sum_{i=1}^{n} \sum_{k=1}^{k} \delta_k z_{ik} + \sum_{m=1}^{3} \tau_m d_m + h, \tag{5}$$

where TE_i is the technical efficiency of the i-th household calculated from Equation (4), h is the error term of the efficiency function, z_{ik} is the k-th variable vector that may possibly affect the technical efficiency of the i-th household, and d_m is a dummy variable representing the impact of the differences in technical means, external conditions, and favorable policies on the technical efficiency of agricultural production.

The technical efficiency of agricultural production is influenced by many factors and the inefficiency effects model can be used to identify the variables that influence it. Based on Equation (3), the inefficiency effects model has the following form:

$$u_i = \delta_0 + \sum_{i=1}^{n} \sum_{k=1}^{k} \delta_k z_{ik} + \omega_i, \tag{6}$$

where z_{ik} is the vector of explanatory variables for technical inefficiency, ω_i is a random error term that obeys the extreme value distribution and δ_k is the estimated parameter that represents the impact of the inefficiency variable. If δ_k is a non-negative variable, it has a positive impact on the technical

efficiency of agricultural production. If it is negative, it has a negative impact on the technical efficiency. *n* is the sample size.

2.2.3. Variable Selection

The land consolidation project in the Jiangsu Province has a direct or indirect impact on agricultural production in at least three ways. The first way is through leveling the land and reducing land fragmentation. The second way is through promoting agricultural mechanization and improving crop diversity. The third way is through promoting the urbanization of the rural population and accelerating land tenure transfer. Therefore, variables representing land fragmentation, crop diversity, and land tenure transfer must be included in stochastic frontier analysis (SFA). The average distance from the dwellings to the plots is estimated based on the land use map and the Simpson's index (*SI*), which was used in Chen et al. [69]. This distance is taken as a measure of land fragmentation. *SI* is calculated by Equation (7).

$$SI = 1 - \sum_{i=1}^{n} a_i^2 / \left(\sum_{i=1}^{n} a_i\right)^2, \tag{7}$$

where *n* is the number of plots and a_i is the area of the *i*-th plot. The value of *SI* varies from 0 to 1. *SI* = 0 indicates that the household has only one plot. The larger the value of *SI*, the higher the degree of land fragmentation.

Cropping diversity is widely practiced in rural China. However, since many surveys do not obtain data on the type of crop used on each plot, a dummy variable is used to represent cropping diversity or not. Here, the Herfindahl index (HI) as used in Llewelyn and Williams [70] and Bradshaw [71] is shown by Equation (8):

$$HI = \sum_{i=1}^{m} \left(\frac{a_i}{A}\right)^2 \tag{8}$$

where *m* is the crop type, a_i is the planting area of the *i*-th crop, and *A* is the total planting area of the household. The *HI* value varies from 0 to 1. *HI* = 1 indicates that only one crop is planted. The lower the *HI* value, the higher the crop diversity is.

Promoting rural urbanization is among the key goals of land consolidation in China. This stands in contrast to the situation in Europe at the end of the last century where the goals were to mitigate the outflow of the rural population to the cities and to revive the rural economy [72]. Although the increase of non-agricultural employment can increase household income, it brings uncertainty to the technical efficiency of agricultural production. In the context of HRS, the increase of non-agricultural employment will inevitably promote land tenure transfer either within the family or in the rural community. Here the percentage of rented land is used as a measure of the impact of non-agricultural employment and land tenure transfer on the technical efficiency of agricultural production.

Other factors can also influence the agricultural technical efficiency of producers. First, characteristics of the family members engaged in agricultural production such as the age and educational background of the head of household and support coefficient. Second, an increase in non-agricultural income is usually associated with a reduction in the time spent farming, which leads to a decline in the efficiency of agricultural production. Third, access to external resources and the availability of loans has a crucial impact on the efficiency of agricultural production since it reduces the capital restrictions on agricultural production and management. Fourth, with regard to ownership of agricultural machinery, time is one major limiting factor in agricultural productivity and the use of agricultural machinery can save time and help promote the efficiency of agricultural production. Another factor is whether the household is making use of new technologies and skills for agricultural production and gained government subsidies or enjoyed technical services provided by the government. Table 1 gives a description of all variables considered, as well as the potential impacts of each.

Table 1. Description and potential impacts of all variables considered on the technical efficiency.

Variable	Description	Expected Sign
Gout	Gross output value of agriculture (CNY)	
Sa	Sown area (hectare)	$\pm$
L1	Cost of household labor (CNY/hectare)	+
L2	Cost of hired labor (CNY/hectare)	−
Sc	Cost of seeds (CNY/hectare)	−
Fc	Cost of fertilizers and farm manure (CNY/hectare)	+
Pc	Cost of pesticides (CNY /hectare)	$\pm$
Mc	Cost of rented agricultural machinery and self-owned agricultural machinery (CNY/hectare)	−
Dist	Distance of the plots to the roads or dwellings (m)	−
SI	1-(square of the plot area and/or square of the sum of plot areas)	$\pm$
HI	Sum of the squared percentage of land grown with each crop to total planting area	$\pm$
Age	Age of the head of household	−
Edu	Schooling years of the household (year)	+
Hl	Number of household laborers	+
Hnl	Number of non-laborers in the household	−
Pnfi	Percentage of non-agricultural income to total income (%)	+
Dmec	Owning agricultural machinery = 1, owning no agricultural machinery = 0	−
Dcred	Getting the loans =1, not getting the loans = 0	−
Dsci	Using new agricultural technologies = 1, not using new agricultural technologies = 0	−
Dsj	Located in southern Jiangsu=1, not located in southern Jiangsu = 0	$\pm$

Note: − indicates expected negative impact, + indicates expected positive impact, $\pm$ indicates uncertain impact.

2.2.4. Model Estimation and General Descriptive Analysis

Even though Equation (4) has linear characteristics, it does not satisfy the typical assumptions of the least squares method since the error term of the regression equation contains two non-observable variables. Therefore, the OLS regression is not feasible. We used the one-stage approach by which the household characteristics influencing technical efficiency are included in the production frontier function. Following Battese and Coelli [68] and Coelli et al. [73], it is assumed that u_i is determined by the vector of exogenous variables Z_i, i.e., $u_i = (\gamma\prime Z_i + \varepsilon_i) \geq 0$, $\varepsilon_i \sim N(0, \sigma_\varepsilon^2)$ and the distribution of ε_i has $-\gamma\prime Z_i$ as an upper limit. At this time, $\mu_i \sim N^+(\gamma\prime Z_i, \sigma_\varepsilon^2)$. Assuming the distribution patterns of v_i and u_i, all parameters can be obtained by a maximum likelihood estimation. The model estimation was conducted with Stata11 software (https://www.stata.com/stata11).

Table 2 shows the results of general descriptive statistics for different variables. Total costs contain the cost of household labor (L1), hired labor (L2), seeds (Sc), fertilizers and farm manure (Fc), pesticides (Pc) and rented agricultural machinery and self-owned agricultural machinery (Mc). Labor costs, which refer to the cost of household labor (L1) and hired labor (L2), are the most important, which account for 34.3% and 35.0% of total cost in the years 2010 and 2015, respectively. The costs of fertilizers (Fc) and agricultural machinery (Mc) come next. As the rented land area per household (Sa) increased, the cost of hired labor (L2) and agricultural machinery (Mc) also increased. The rise in prices for each factor of production further reduces the profit margin of agricultural production, which dampens the farmers' motivation for farming.

After land consolidation, the average distance from dwellings to the plots also decreases by 200 m, which demonstrates an improvement of the road network. The Simpson's index (SI) declined from 0.74 in 2010 to 0.54 in 2015, which is equivalent to an average reduction from four plots to two plots per household. The Herfindahl index (HI) increased from 0.29 in 2010 to 0.47 in 2015, which shows a decline in crop diversity after land consolidation. These results indicate that land consolidation has a significant impact on land use pattern [15,24]. This might be related to an increasing use of agricultural machinery, which reduces planting diversity after improving agricultural production infrastructure. The percentage of rented land area (Sa) increased rapidly between 2010 and 2015 for two reasons including the increase of non-agricultural employment and land tenure transfer ratio after land consolidation. This in turn led to the increase of non-laborers (Hn1) in no rented land household. The ages of the head of household and schooling years of the household have not a significant change after land consolidation. However, the ages of the head of rented land producers are younger than that of no rented land producers, and schooling years of rented land producers are longer than that of no rented land producers.

Table 2. General descriptive statistics of output and all the variables in this study.

Variables	Coefficient (Std. Error) in 2010			Coefficient (Std. Error) in 2015		
	All Samples	No Rented Land Producer	Rented Land Producer	All Samples	No Rented Land Producer	Rented Land Producer
Gout	15,386.52 (48,061.40)	8045.34 (21,217.05)	37,763.01 (84,085.51)	31,845.62 (78,932.08)	7902.45 (19,945.78)	52,176.67 (137,541.80)
Sa	0.57 (0.22)	0.31 (0.13)	1.36 (0.51)	1.06 (0.39)	0.30 (0.15)	1,1 (3.54)
L1	2314.08 (2987.90)	2353.37 (3218.55)	2194.32 (6324.15)	2131.45 (3324.54)	2237.17 (3425.78)	2041.68 (3219.41)
L2	675.29 (3028.96)	248.05 (987.05)	1977.56 (5142.33)	3809.34 (8476.55)	214.78 (875.53)	6861.62 (13127.91)
Sc	561.71 (1237.89)	400.08 (1137.05)	1054.36 (1726.81)	1122.57 (1857.34)	375.49 (1031.17)	1756.94 (3318.91)
Fc	2018.52 (4157.82)	1116.43 (2347.57)	4768.16 (15,781.41)	3927.90 (10,245.89)	1034.87 (2987.65)	6384.48 (12,094.56)
Pc	756.42 (1812.40)	466.13 (1733.49)	1641.24 (3277.19)	1402.65 (1953.12)	479.87 (1890.43)	2186.22 (3544.81)
Mc	2394.83 (15,067.38)	1442.62 (1956.81)	5297.24 (21334.57)	4584.76 (1871.23)	1659.87 (3218.74)	7068.40 (14,331.24)
Dist	813.40 (2327.86)	818.89 (2546.97)	796.67 (1924.56)	605.20 (1021.36)	512.31 (724.12)	684.08 (1231.45)
SI	0.74 (0.13)	0.73 (0.12)	0.77 (0.15)	0.54 (0.14)	0.60 (0.16)	0.49 (0.13)
HI	0.29 (0.17)	0.21 (0.16)	0.53 (0.21)	0.47 (0.15)	0.30 (0.14)	0.61 (0.16)
Age	56.60 (14.30)	57.4 (14.24)	54.2 (17.17)	58.80 (13.60)	60.10 (11.80)	57.7 (16.9)
Edu	7.21 (3.25)	6.64 (3.14)	8.95 (3.89)	7.63 (3.17)	6.31 (2.98)	8.75 (3.58)
Hl	2.52 (1.31)	2.23 (1.07)	3.40 (2.97)	2.03 (1.42)	1.45 (0.98)	2.52 (2.15)
Hnl	0.67 (0.19)	0.86 (0.37)	0.09 (0.05)	1.20 (0.34)	1.74 (0.67)	0.74 (0.23)
Pnfi	41.20 (178.44)	51.50 (195.63)	9.80 (17.86)	60.36 (306.40)	88.21 (351.24)	36.71 (104.56)
Dmec	0.18 (0.32)	0.09 (0.09)	0.45 (0.39)	0.29 (0.40)	0.09 (0.13)	0.46 (0.49)
Dcred	0.16 (0.36)	0.08 (0.11)	0.40 (0.51)	0.26 (0.44)	0.07 (0.10)	0.42 (0.57)
Dsci	0.06 (0.10)	0.04 (0.09)	0.12 (0.23)	0.09 (0.14)	0.04 (0.07)	0.13 (0.21)
Dsj	0.13 (0.24)	0.10 (0.17)	0.22 (0.37)	0.14 (0.21)	0.09 (0.13)	0.18 (0.29)
Number of Producer	842	634	208	858	394	464

Furthermore, according to the surveys, only 18% of producers own large-scale agricultural machinery (Dmec) and have acquired loans (Dcred). New agricultural varieties, farming technologies, and management skills all require agricultural machinery and funds [24,39,45]. In the long run, credit might meet farmers' funding demands, which would enable effective agricultural operation and management.

3. Results and Discussion

3.1. Hypothesis Testing and Variance Parameters of the Stochastic Frontier Production Function

The null hypothesis, $H_0 = \delta_0 = \delta_1 = \ldots = \delta_i = 0$, states that there is no inefficiency effect in gross output value of agriculture (Table 3). Since the calculated value using a log-likelihood ration (LR) test is higher than the tabulated value, this hypothesis is rejected for both models at a 1% level of significance. This implies that there are significant technical inefficiency effects in gross output value of agriculture (Table 4). $LR = -2[lnL(H_0) - lnL(H_1)] \sim x^2(J)$ where $lnL(H_0)$ and $lnL(H_1)$ are log-likelihood functions of two different regularity conditions in the frontier model and J is the amount of conditions. The hypothesis testing result of the one-sided error 32.7 ($p < 0.01$) rejected the null hypothesis and significantly improved the appearance of the full specification against the χ^2 (6, 0.99) value of 15.9. Similarly, the null hypothesis where land consolidation was jointly zero in full specification was also rejected, which indicates that land consolidation significantly affected agricultural output of producers and it is worth including this in the full specification.

Table 3. Regularity conditions checks.

Hypothesis	Critical Value of χ^2 (d.f., 0.99)	Before Land Consolidation		After Land Consolidation	
		LR Statistic	Decision	LR Statistic	Decision
Specification before land consolidation variables is enough	15.9	0	0	32.7 ***	reject
No effect of land consolidation on output (H_0: $\beta_1 = \beta_2 = 0$)	8.4	0	0	14.4 ***	reject
No presence of technical inefficiency (H_0: $\gamma = 0$)	6.5	18.8 ***	reject	14.1 ***	reject
Constant return to scale in production (H_0: $\alpha_1 + \alpha_2 + \alpha_3 = 1$)	15.1	40.4 ***	reject	56.9 ***	reject
No effect of managerial variables on efficiency (H_0: $\delta_1 = \delta_2 = \ldots = \delta_{19} = 0$)	21.9	29.7 ***	reject	34.5 ***	reject

Notes: The likelihood ratio test was significant at the 99% significance level. *** 99% significant level. The same below.

The null hypothesis test of the inefficiency effect was strongly rejected in both models by the LR tests, which are depicted in Table 3. The γ values support the rejection of the previous null hypothesis when the γ values are statistically significant at the 1% level of significance in a *t*-test, which means that about 82.7% and 78.8% (Table 4) of the variation in agricultural output, respectively, is due to technical inefficiency rather than a random variability among producers and that most households operate below a technically efficient threshold. The estimated coefficient can be directly served as the elasticities while agricultural output was expressed as the Cobb–Douglas production function. The total elasticity of the stochastic frontier function represents the proportionate changes in output if the inputs change after land consolidation. The hypotheses testing the zero joint effect of the managerial factors of the producers was rejected for specifications before and after land consolidation at the 1% level of significance, which indicates that the technical efficiency level of agricultural output mainly relies on managerial factors among producers.

As shown in the upper half of Table 3, agricultural output increases due to changes in the sown area, the cost of hired labor, and rented agricultural machinery. However, household laborers, the cost of seeds, fertilizers, and pesticides are negative, which indicates that the output decreases with a higher input of these factors. The increase of hired labor and rented agricultural machinery cost was significantly correlated with output in rented land producers, which was not observed in the case of no rented land producers. Due to the scale effect, the large-scale producers can enjoy a discount on fertilizers, pesticides, and machinery services or can even buy these factors on credit. What is contrary to expectations is that the output elasticity of seed cost is negative and significant at the 10% significance level. However, this finding is in agreement with the research of Feng and Heerink [44]. This is probably because Chinese farmers tend to keep the seeds for themselves and more seeds do not lead to a greater yield. Therefore, further research on the characteristics of seeds is needed.

Table 4. Maximum-likelihood estimates for the parameters of the Cobb–Douglas stochastic production function.

Variables	Coefficients (S.E.) without Land Consolidation Effects in 2010			Coefficients (S.E.) with Land Consolidation Effects in 2015		
	Total	**No Rented Land Producer**	**Rented Land Producer**	**Total**	**No Rented Land Producer**	**Rented Land Producer**
	Production Function					
ln(Sa)	1.009 *** (0.035)	0.711 *** (0.049)	1.142 *** (0.029)	1.185 *** (0.033)	0.703 ***(0.047)	1.473 *** (0.039)
ln(L1)	−0.019 (0.013)	−0.047 (0.019)	0.003 (0.009)	−0.013 (0.0017)	−0.051 (0.019)	0.002 (0.011)
ln(L2)	0.083 *** (0.028)	0.002 (0.009)	0.105 ***(0.024)	0.103 *** (0.029)	0.003 (0.013)	0.117 *** (0.028)
ln(Sc)	−0.027 * (0.013)	−0.013 (0.009)	−0.029 * (0.017)	−0.024 * (0.011)	−0.011 (0.010)	− 0.027 * (0.017)
ln(Fc)	−0.007 (0.011)	−0.010 (0.009)	−0.003 (0.013)	−0.009 (0.013)	−0.013 (0.011)	−0.005 (0.010)
ln(Pc)	−0.017 (0.019)	−0.019 (0.017)	0.000 (0.009)	−0.013 (0.015)	−0.021 (0.017)	−0.002 (0.010)
ln(Mc)	0.013 * (0.011)	0.005 (0.007)	0.041 ** (0.019)	0.047 ** (0.021)	0.009 (0.013)	0.087 *** (0.032)
Dummy of Project Variable			*Controlled*			
Constant	6.857 *** (0.625)	5.587 *** (0.478)	7.726 *** (0.598)	7.245 *** (0.731)	4.985 *** (0.612)	7.988 *** (0.773)
	Technical Inefficiency Effects Function					
ln(Dist)	0.027 (0.017)	0.023 (0.011)	0.029 (0.019)	0.031 (0.019)	0.034 (0.015)	0.029 (0.019)
ln(SI)	−0.119 *** (0.084)	−0.043 ** (0.037)	−0.178 *** (0.101)	−0.025 (0.015)	−0.027 (0.019)	−0.018 (0.012)
ln(HI)	0.286 *** (0.037)	0.417 *** (0.051)	0.212 *** (0.035)	0.142 *** (0.028)	0.237 *** (0.031)	0.029 * (0.017)
ln(Age)	−0.027 (0.103)	−0.031 (0.149)	-0.008 (0.034)	−0.034 (0.171)	−0.038 (0.154)	−0.015 (0.045)
ln(Edu)	0.023 (0.054)	0.019 (0.037)	0.034 * (0.109)	0.024 (0.051)	0.017 (0.021)	0.031 * (0.038)
ln(Hl)	0.021 (0.027)	0.017 (0.015)	0.029 (0.078)	0.017 (0.019)	0.011 (0.015)	0.023 (0.055)
ln(Hnl)	−0.021 (0.042)	−0.029 (0.101)	−0.009 (0.028)	−0.019 (0.039)	−0.024 (0.056)	−0.003 (0.009)
ln(Pnfi)	0.239 *** (0.074)	0.371 *** (0.224)	0.218 *** (0.185)	0.227 *** (0.109)	0.456 *** (0.387)	0.196 *** (0.132)
Dmec	0.019 (0.042)	0.011 (0.018)	0.037 * (0.087)	0.021 (0.058)	0.012 (0.019)	0.034 * (0.085)
Dcred	0.017 (0.037)	0.013 (0.019)	0.031 * (0.059)	0.018 (0.041)	0.011 (0.015)	0.037 * (0.072)
Dsci	0.021 (0.034)	0.007 (0.013)	0.026 (0.039)	0.019 (0.024)	0.003 (0.009)	0.025 (0.042)
Dsj	−0.031 (0.045)	−0.024 (0.034)	−0.041 (0.059)	−0.027 (0.037)	−0.019 (0.025)	−0.034 (0.048)
Constant	−1.594 (1.487)	−1.311 (1.093)	−2.118 (1.593)	−1.035 (1.124)	−1.217 (1.404)	−0.955 (1.012)
	Model Diagnostics					
$\sigma = \sigma_v + \sigma_u$	0.107 *** (0.045)	0.101 ***(0.038)	0.073 *** (0.029)	0.104 *** (0.038)	0.067 *** (0.035)	0.092 *** (0.046)
$\gamma = \sigma_u^2/(\sigma_v^2 + \sigma_u^2)$	0.827 *** (0.162)	0.803 *** (0.147)	0.754 *** (0.136)	0.788 *** (0.134)	0.764 *** (0.132)	0.741 ***(0.124)
LF [1]	425.07	317.87	123.75	532.48	289.78	324.58
NH [2]	0.023	0.029	0.021	0.019	0.017	0.021
TN [3]	842	634	208	858	394	464

Note: [1] LF means Log-likelihood Function; [2] NH means Null Hypothesis: No Inefficiency Effects in SFA (*p*-value); [3] TN means Total Number of Observations. The likelihood ratio test was significant at the 99% significance level. * 90% significant level, ** 95% significant level, *** 99% significant level. The same below.

3.2. Technical Efficiency Estimates and Econometric Results Analysis

Technical efficiency was calculated by using Equation (5). The household sizes were classified by the following criteria: a small farm household was defined as ownership of less than 1 ha of farmland, a medium-sized farm household was defined as ownership of 1–2 ha of farmland, and a large farm household was defined as ownership of more than 2 ha of farmland. The size thresholds in this study are smaller than the FAO [74]. This is because few households own farmland above 2 ha in China. As shown in Table 5, the overall technical efficiency of the household increased from 0.84 in 2010 to 0.92 in 2015, which indicates that 91.0% of the potential output can be realized by combining the current factors of production. However, a higher technical efficiency of the household does not necessarily mean a higher actual efficiency, which is consistent with the assumption of a constant return to scale. This is different from the conclusions of Fleisher and Liu [27], Tan et al. [30] and Wouterse [43]. According to the field surveys, large-sized farm households need to hire more laborers and the efficiency of the hired laborers is generally lower than that of household laborers. Moreover, large-sized farm households often rent plots, which are very far from the dwellings. This leads to a higher risk of a scattered distribution of plots.

Table 5. Technical efficiency of producers of different sizes.

Catalog	2010				2015			
	<1 ha	1–2 ha	>2 ha	Total	<1 ha	1–2 ha	>2 ha	Total
Max	0.99	0.98	1.00	1.00	0.99	0.99	1.00	1.00
Min	0.54	0.62	0.61	0.54	0.56	0.64	0.62	0.56
Mean	0.78	0.86	0.87	0.84	0.85	0.94	0.91	0.92
SD	0.06	0.05	0.02	0.05	0.05	0.04	0.02	0.05

Technical efficiency econometric results analysis was shown at the bottom half of Table 4. The coefficients of HI and Pnfi are positive at the 1% significance level before and after land consolidation, but the coefficient of SI is negative at the 5% significance. The variables of Edu, Dmec, and Dcred are significant at the 10% significance level in rented land producers and the coefficient is negative. A higher educational level usually means greater opportunities for non-agricultural employment, which leads to less time in agricultural management. The number of household laborers has no significant impact on technical efficiency in this survey. This result is contrary to previous research [30,75]. The coefficient of Dmec is positive and this variable is significant at the 10% significance level in rented land producers, which indicates that owning agricultural machinery in rented land producers can promote agricultural technical efficiency. Whether a loan is acquired or not, and whether new farming technologies and skills are applied, are represented by two dummy variables. The coefficients are positive but not significant for both. According to the field surveys, few small and medium-sized farm households require loans. They can buy fertilizers and pesticides on credit. The larger-sized farm households can enjoy more favorable loan policies. However, households considered as "having taken advantage of new farming technologies and skills" are required to do no more than distribute information on pest and disease control and prevention in order to acquire favorable loans. The regional dummy variable is not significant, which indicates that farm households in the more economically developed Southern Jiangsu are not particularly motivated to rent more land.

3.3. Impacts and Policy Insights from Land Consolidation

Land consolidation promotes land tenure transfer in China. According to the survey, the coefficient of the percentage of rented land is positive, indicating that households are free to rent the land through an unobstructed land tenure transfer, which is conducive to increase the overall technical efficiency. The elasticity of this variable does not increase dramatically in rented land producers after land consolidation, which indicates that the technical efficiency of producers does not increase indefinitely

with sown size. Instead, if the sown size is too large, technical efficiency will be impaired. This supports the assumption of a constant return to scale and is in agreement with the conclusion of Fleisher and Liu [27]. The promotion of land consolidation on land tenure transfer also reported in the studies of Liu et al. [76] in China, Van Hung et al. [35] in Vietnam, Vitikainen [77] in Europe, and Niroula and Thapa [11] in South Asia.

Land consolidation reduces farmland fragmentation. This phenomenon is directly indicated by the increase of snow area and decrease of Simpson's Index (SI) after land consolidation. And the SI is not statistically significant, which indicates the inverse relationship between technical inefficiency and farmland fragmentation. Previous studies recorded that land consolidation dealt with the problems of land fragmentation in China [6,28]. Also in Europe, many hundreds of farmlands have been reallocated over the years in the government framework of land consolidation projects, to some extent at least, farmland fragmentation was solved [3,5,77,78].

Land consolidation decreases cropping diversity. In either the profit model or the inefficiency effect model, Herfindahl index (HI) can promote efficiency, which agrees with the field surveys and research conducted by Nel and Loubser [79] and Rahman [80]. However, HI has the opposite impact on the gross output value of agriculture in the Jiangsu Province. Since non-agricultural employment took up a large number of laborers after land consolidation, the average cost per area of labor, fertilizers, pesticides, and rented agricultural machinery have dropped dramatically, which increased the profitability of farms. Since mechanized farming has become more popular in the Jiangsu Province, the manual labor supply is no longer the limiting factor [6]. In China, the non-agricultural employment rate is usually high in developed regions where people spend more time on non-agricultural activities and, therefore, prefer mechanized and simplified farming practices [30]. As a result, it is a reduction in cropping diversity. This finding is consistent with Niroula and Thapa [11], Rahman and Rahman [39], Wu et al. [55] and Karelakis and Tsantopoulos [59].

According to the above analysis of implication of land consolidation projects, some policy insights for improving agricultural technical efficiency are as follows.

First, along with the clarification of rights of usufruct and land property rights structure, the most urgent and most attainable mission for the government is to create more non-agricultural employment to increase the non-agricultural income and to reduce the farmers' dependence on land. This is an indispensable link in making land no longer a limiting factor of production. As more farmers give up farming, the plots can be merged and the scale of production will be increased for the remaining farmers. Farmers who have renounced their land property rights or traded high-quality plots for poor-quality ones should be adequately compensated. Alternatively, preferential tax policies, loan policies, and subsidies for factors of production can be used to facilitate land tenure transfer.

Second, land consolidation should be employed as an effective tool for promoting agricultural development and farmers' income. Land consolidation is conducive to the improvement of the technical efficiency of agricultural production and to the protection of agricultural resources and the environment. The relevant authorities should promote the exchange of agricultural information and loan support to the farming households in the construction of high-standard basic farmland.

Lastly, increasing investment in agricultural infrastructures and enhancing the positive externalities of constructed infrastructure can weaken the adverse impact of land fragmentation on agricultural technical efficiency. Land consolidation is an effective means of improving crop quality and yield as well as farmers' income. Therefore, promoting large-scale land consolidation not only creates a favorable environment for popularizing mechanized farming but also facilitates the transformational development of agriculture towards higher efficiency and more stable yields. This is an important measure for safeguarding national food production.

4. Conclusions

In the context of accelerated land tenure transfer, increasing non-agricultural employment, and popularization of mechanized farming, we randomly selected 30 projects for constructing

high-standard basic farmland, which were implemented from 2009 to 2011. The sampling was performed at two time points during July 2010 and July 2016. For each project, 30 farm producers were selected at random. The agricultural input and output, cropping system, land rental, family characteristics, and land right property structure were surveyed. Then, using SFA, the impacts of land rental, land fragmentation, and crop diversity on the profitability and technical efficiency of production were assessed. The main conclusions are described below.

First, as indicated by the descriptive statistics, dramatic changes have taken place in local land tenure transfer, land fragmentation, and crop diversity after land consolidation, which inevitably affects agricultural technical efficiency. Regressions using a stochastic frontier function with predictive factors indicate significant negative correlations for land fragmentation and crop diversity on a technical efficiency level.

Second, the overall technical efficiency of the producer increased considerably after land consolidation. Furthermore, 92.4% of the potential output can be achieved by combining the existing factors of production. As land fragmentation decreased dramatically through the accelerated land tenure transfer, households who remained to farm the land were free to rent it to others. This promoted an increase in agricultural technical efficiency.

Third, no significant discrepancy exists between the technical efficiency of rented land when compared with self-owned land. However, given the low levels of managerial experience as well as lack of agricultural machinery and technical services in rural China, a scale of production that is too large will decrease technical efficiency.

Fourth, the higher the non-agricultural income, the higher the technical efficiency of agricultural production is. An increase in non-agricultural employment cannot only absorb rural surplus labor but also increases the farmers' income and promotes technical efficiency. In addition, food security and land tenure transfer can be promoted as well.

Fifth, although higher crop diversity is conducive to improving agricultural technical efficiency, crop diversity was found to decrease after land consolidation in China because of the popularization of large-scale mechanized farming. As costs of manual labor are reduced by mechanized farming, the decreased crop diversity causes an increase of agricultural technical efficiency in practice.

These conclusions would be helpful in understanding the impacts before and after land consolidation, and improving the implementation efficiency of land consolidation in China and other developing countries.

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