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# Can the outsourcing improve the technical efficiency of wheat production with fertilization and pesticide application? Evidence from China

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A R T I C L E I N F O

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A B S T R A C T

Fertilizer and pesticide inputs (FPI) can provide the growth of wheat production while causing environmental pollution and agri-product quality decline. Agricultural production outsourcing has been introduced to solve the above-mentioned dilemmas. It is noteworthy whether agricultural production outsourcing can improve technical efficiency (TE) by optimizing resource allocation. The study aims to examine the effect of outsourcing of fertilization and pesticide application (OF and OPA) on TE. It also tests moderating effect of plot and contiguous cropping (CC) based on 1018 farmers from three provinces. The results demonstrated: (a) The cost OF and OPA had a negative and then positive impact on TE. (b) The moderating effects of plot and CC were tested. (c) Smaller-than-average groups were more sensitive to cost of the OF and OPA. The findings implied: (a) Negative effect of outsourcing can be mitigated by formulating a standard for application of fertilization and pesticide and developing an insurance market. Training should be provided so that farmers can choose the appropriate times of outsourcing. (b) High-standard farmland construction and CC are essential strategic orientation in agricultural development. (c) Farmers with different endowments should be guided to reasonably purchase OF and OPA, and subsidy should be provided.

## 1. Introduction

Wheat is one of the two major staple grains in China. The wheat sown area accounted for 20.02% of grain cropping and its production accounted for 20.05% of the total grain production in 2020. 40% of grain consumption relies on wheat as a staple food in China. Wheat production has increased from 54 to 134 million t and yield has increased from 1.84 to 5.74 t/ha from 1978 to 2020.[1] Undoubtedly, the grain production sustainably improvement safeguards national food security accompanying the increase in fertilizer and pesticide inputs (FPI) (Ren et al., 2021). Fertilizer has been reported to contribute more than 40% of the increase in grain production.[2] However, the quantity of FPI can lead to soil pollution, water eutrophication, and greenhouse gas emissions, and affect the quality of agricultural products (Tilman et al., 2001; Uphoff and Dazzo, 2016; Wauters et al., 2010; Yang et al., 2020). Fertilizer inputs of wheat were 0.42 t/ha in 2020.[3] Partial provinces have experienced excessive inputs of fertilizer in wheat production (Huang and Jiang, 2019). The utilization rate of pesticide is only 35%,[4] and the phenomenon of non-standard input is widespread. Based on the current situation, the Chinese government has taken countermeasures to control FPI,[5] such as organic fertilizer instead of chemical fertilizer, soil testing for formulated fertilization, green prevention and control, and so on (Li et al., 2021, 2022).

However, the above-mentioned countermeasures have faced some challenges in their promotion. Agricultural mechanization has been

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[1] 2021 China Statistical Yearbook (http://www.stats.gov.cn/tjsj/ndsj/2021/indexch.htm).

[2] http://www.moa.gov.cn/nybgb/2015/san/201711/t20171129_5923401.htm.

[3] 2021 China Agricultural Cost-Benefit Information Compilation.

[4] http://www.moa.gov.cn/nybgb/2015/san/201711/t20171129_5923401.htm.

[5] http://www.moa.gov.cn/govpublic/ZZYGLS/202212/t20221201_6416398.htm.http://www.moa.gov.cn/zxfile/reader?file=http://www.moa.gov.cn/govpublic/FZJHS/202109/P020210907501175710523.pdf.

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**Nomenclature**

| | |
|---|---|
| SFA | stochastic frontier approach |
| DEA | data envelopment analysis |
| TE | technical efficiency |
| OF | outsourcing of fertilization |
| OPA | outsourcing of pesticide application |
| CC | contiguous cropping |
| FPI | fertilizer and pesticide inputs |
| UAV | unmanned air vehicle |
| DMUs | decision-making units |
| NIP | new inflection point |

reducing the farmers' labor intensity and improving the efficiency of agricultural production significantly. However, it is difficult for smallholders to bear the initial cost of mechanical inputs (Mi et al., 2020). On the other hand, some farmers engaged in agricultural production in rural China are elderly or women. They have a little cognition of green agricultural production practices and have difficulty obtaining green inputs such as organic fertilizer and insecticidal lamps (Wan and Zhong, 2020; Wang et al., 2017; Yang and Sang, 2020). Therefore, some farmers outsource fertilization and pesticide application to cooperatives or large-scale farmers. Outsourcing is based on specialization and separability of the agricultural production stage, where farmers can hire others to complete parts or all of the production practices (Hallam, 2011; Sepehri and Sarrafzadeh, 2018; Tan et al., 2008; Zhang et al., 2017). Outsourcing decision and the effects have attracted great academic attention on agriculture production. Studies have proved that the decision to outsource is restricted by relevant factors, including farmers' endowments as well as the external environment. For example, age, education level, number of family labor, family income, degree of land fragmentation, etc. are important decision references for farmers' outsourcing. (Qian et al., 2022; Qiu et al., 2021). In addition, studies have found that outsourcing has significant changes such as alleviating the farmers' financial pressure, improving the efficiency of machinery and FPI utilization, reducing labor intensity, increasing the agricultural production and technical efficiency (TE), and improving household welfare (Deng et al., 2020; Lyne et al., 2018; Mi et al., 2020; Qing et al., 2023; Zhou et al., 2020). It also prevents threats for human health by improper FPI (Amuakwa-Mensah and Surry, 2022; Reerink and van Gelder, 2010; Wang et al., 2017). However, outsourcing suffers from principal-agent, which farmers may face the risk of opportunistic behavior from outsourcing providers (Gailmard, 2009; Kim, 2020). Therefore, how does outsourcing of fertilization and pesticide application (OF and OPA) affect wheat production and how are the effects measured?

TE reflects the gap between the actual input and output allocation status and the ideal allocation status, which has been applied to measure grain productivity in numerous agricultural researches (Benedetti et al., 2019; Khanal et al., 2018; Watto and Mugera, 2015). Studies focused on the effect of agricultural production outsourcing on TE and its heterogeneity at stages. It can be testified that outsourcing in labor-intensive stages enhances TE, but there is a controversy about the effect OF and OPA on TE (Lu et al., 2020; Picazo-Tadeo and Reig-Martinez, 2006; Sun et al., 2016; Yang and Cai, 2020; Zhu and Gu, 2021). The reason may be that they mostly use binary variable to measure OF and OPA, which leads to inconsistent conclusions about their effect on TE. In addition, the per capita arable land is small and fragmented in rural China. It is necessary to promote "merging small plots into large ones" to reduce the negative effect of land fragmentation on high-quality development of agriculture.[6] How is the effect of agricultural production outsourcing on TE will be affected. Therefore, plot of arable land and contiguous cropping (CC) are introduced as moderation factors to discuss the variation in the effect OF and OPA on TE. The literature will be enriched by clarifying the divergence in the effect OF and OPA on TE and revealing the moderating effect of plot and CC. In reality, the expected results of the study can promote agricultural green production transition, while contributing to policymakers and practitioners in adjusting extension programs of agricultural production outsourcing or developing more innovative agricultural initiatives.

The paper aims to make progress in the following three aspects: (1) to calculate TE for farmers from Shanxi, Shandong, and Henan, (2) to examine the effect of the OF and OPA on TE, and (3) to investigate the moderating effect of the plot and CC.

In addition, the paper can be organized as follows. The second section introduces the theory and hypotheses, including the research framework. The third section expounds on the study region, data collection, and econometric models, while the fourth section presents the results. The fifth section includes discussions and implications. The conclusions are set in the final section.

## 2. Theoretical and hypotheses

### 2.1. Agricultural production outsourcing and TE

The division of labor in agriculture was first discussed by Adam Smith. The deeper the division of labor, the higher the specialization level and production efficiency of each stage (Smith, 1776). OF and OPA are typical of the division of labor in agriculture, and their effect on TE is supported by relevant theories. On the one hand, fertilization and pesticide application need to be conducted several times with intensive technology in wheat production. There is a lag in effect evaluation, which leads to the principal-agent dilemma (Gailmard, 2009; Kim, 2020). Outsourcing providers pursue to maximize economic revenue, which can lead to opportunistic behaviors. Farmers may lack expertise in evaluation, which increasing the probability of opportunistic behavior of outsourcing providers, and over-supervise resulting in excessive inputs. These can lead to TE decline. On the other hand, OF and OPA have positive effect on TE through labor substitution and technology-inducing under the premise that agricultural production stages can be separated (Feenstra and Hanson, 1996; Prahalad and Hamel, 1990). OF and OPA can replace relatively expensive labor with relatively cheap machinery, alleviating the labor constraints of agricultural activities. OF and OPA introduce advanced technologies such as unmanned air vehicles (UAVs), which can improve the utilization efficiency of FPI. In conclusion, OF and OPA have both positive and negative effect on TE in the literature.

The cost OF and OPA is regarded as the key to explaining the above differences in the study. When the cost OF and OPA is less, its positive effect on TE cannot offset the negative effect, so the combined effect is negative. As the cost OF and OPA increases, the advantages of labor substitution and technology-inducing effect become more apparent and show a positive effect on TE after a certain inflection point. Ultimately, the cost OF and OPA is necessarily limited to a relatively rational boundary due to the limitations of farmers' endowments. It cannot represent an infinite positive effect of infinitely high cost OF and OPA on TE. The following hypothesis is hereby developed:

**H1**. The cost of OF and OPA has a negative and then positive impact on TE.

[6] http://www.moa.gov.cn/ztzl/2023yhwj/2023nzyyhwj/202302/t20230214_6420535.htm.

### 2.2. The moderating effect of the plot and CC

While still limited by land fragmentation, China has made significant achievements in agricultural production (Ji et al., 2017; Yin et al., 2022). The number of plots represents the degree of land fragmentation, which refers to farmers owning non-contiguous and small-scale arable land. It affects the area and transaction frequency OF and OPA and affects the amount and allocation efficiency of factor inputs. This indicates that the plot moderates OF-TE and OPA-TE. On the one hand, land fragmentation makes it difficult to operate machinery while the marginal cost of outsourcing providers is high. The positive effect OF and OPA on TE is weakened. On the other hand, the times OF and OPA increase because of land fragmentation, which the principal-agent is more serious. The negative effect OF and OPA on TE is enhanced. Accordingly, the following hypothesis is proposed:

**H2**. The plot has moderating effect on OF-TE and OPA-TE, shifting their inflection points to the right.

To address land fragmentation, the "China High-Standard Farmland Construction Plan" proposes to form moderately contiguous plots through land consolidation.[7] The CC is defined as contiguous plots cropping the same grain. It can increase the market capacity of outsourcing (Zhang and Luo, 2020). On the one hand, the CC enables farmers to be involved in the vertical division of labor, which can share scale economies and improve the precision of machinery operation. The marginal cost of outsourcing providers becomes lower while the positive effect OF and OPA on TE is enhanced. On the other hand, the need for OF and OPA decreases due to CC while the principal-agent is reduced. The negative effect OF and OPA on TE is weakened. Based on the above analysis, the following hypothesis is proposed:

**H3**. The CC has moderating effect on OF-TE and OPA-TE, shifting their inflection points to the left.

## 3. Material and methods

### 3.1. Study region

The study was conducted that Shanxi, Shandong and Henan, as the major wheat production areas, were selected as the outsourcing study (Fig. 2). The wheat sown area accounts for about 43.39%, the total production accounts for about 48.85% in China.

### 3.2. Data collection

#### 3.2.1. Questionnaire

Questionnaire design followed the theoretical framework shown in Fig. 1. Farmers' business characteristics, understanding and stage of outsourcing in wheat production were considered. A professional team consisting of one professor, two associate professors, and five doctoral students was assembled to check the items of the questionnaire to make it easy to understand.

#### 3.2.2. Survey

The cross-section data collected by field survey. To ensure the representativeness and objectivity, the survey adopted a combination of stratified sampling and random sampling to select the respondents. In the end, a total of 105 villages were surveyed. A total of 1018 valid farmers were collected. The survey was conducted through face-to-face interviews between the researcher and the respondents. The questionnaire content was the information of the surveyed families in 2020 to ensure the consistency. The Stata 16 was applied to conduct the analyses.

#### 3.2.3. Reasonableness test of sample size

According to Wang et al. (2016), when the number of potential respondents is large enough, the necessary connection does not exist between the minimum sample size available for the study and the total population. At this time, it can be only affected by error and confidence level. The minimum sample size can be calculated by formula (1):

$$n = Z^2\sigma^2 / d^2 \tag{1}$$

where $n$ represents the sample size. $Z$ represents the statistics under a certain level of confidence. $\sigma$ is the standard deviation of the population and is usually set to 0.5. $d$ is the allowable error. In general, a 90% confidence level and a 3% allowable error are appropriate for the samples. Therefore, the minimum sample size is 752, which verifies that the study sample size is adequate.

### 3.3. Methodology

#### 3.3.1. Stochastic Frontier Approach (SFA)

The Data Envelopment Analysis (DEA) and Stochastic Frontier Approach (SFA) have been widely applied to measure TE. DEA is based on a linear programming technique to measure how efficiently Decision-Making Units (DMUs) utilizes the available inputs to produce an optimal set of outputs (Charnes et al., 1978). There are two advantages of the DEA. First, it is a nonparametric method that does not require setting a specific form of the production function, which avoids the model setting problem. Second, it can measure the efficiency of multi-inputs and multi-outputs. However, DEA is sensitive to outliers, ignores the effect of random errors, and lacks environmental factors (Feng et al., 2021). Compared with the DEA, the parametric SFA is more consistent with the essential characteristics of agricultural production while insensitive to outliers. It is the reason that SFA is selected to measure TE in the study. In SFA, the Cobb-Douglas and the translog production functions are commonly used. The advantages of the former include simpler setup, easier calculation, clearer reflect the relationship between input and output variables, and the results being more accuracy. Therefore, the Cobb-Douglas production function is selected for SFA. The model can be defined as following:

$$\ln Y_i = \beta + \beta_L \ln L_i + \beta_K \ln K_i + (V_i - \mu_i) \tag{2}$$

where $Y$ represents farmers' output, expressed by farmers' wheat output value per unit area in the current year. $L$ represents labor input, expressed by labor days (including self-employment days and employment days). $K$ represents capital input, expressed by the amount of wheat direct input per unit area, including cost on seeds, fertilizer, pesticide, and land rent, etc. $(V - \mu)$ is the mixed error term. $V$ is the random error term which is assumed to be normal distribution. $\mu$ is the non-negative production efficiency loss rate of the farmers. The calculation model of the farmers' TE can be defined as:

$$TE_i = \frac{E(Y_i|\mu_i, Q_i)}{E(Y_i|\mu_i = 0, Q_i)} \tag{3}$$

where $Q$ represents all inputs in the wheat growing process. $E(Y|\mu, Q)$ represents the expected value of actual output. $E(Y|\mu = 0, Q)$ represents the expected value of output on the frontier without technical inefficiency.

#### 3.3.2. Analytical model

*3.3.2.1. Non-parametric estimation.* Locally weighted scatterplot smoothing (LOWESS) is one of the non-parametric estimation methods used to examine the relationship between two-dimensional variables, which can provide a more detailed trend (Fig. 3). There is a non-linear

[7] China High-Standard Farmland Construction Plan (2021–2030) (https://www.ndrc.gov.cn/fggz/fzzlgh/gjjzxgh/202111/P020211102598713060217.pdf).

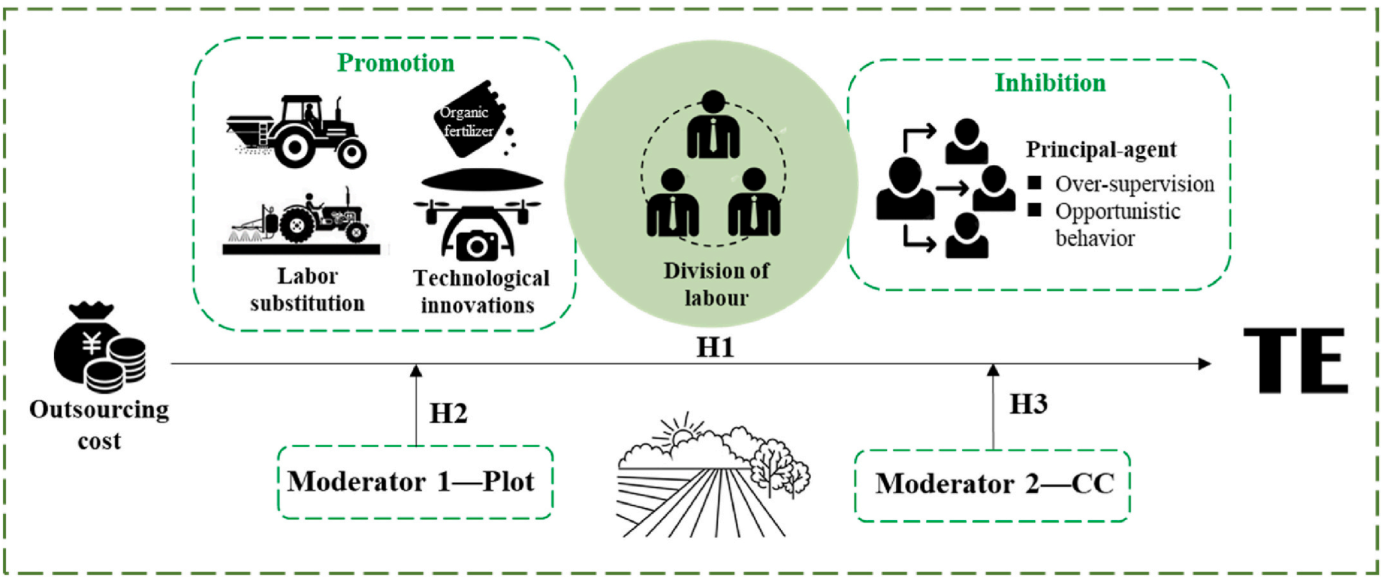


**Fig. 1.** The theoretical framework and the hypotheses.

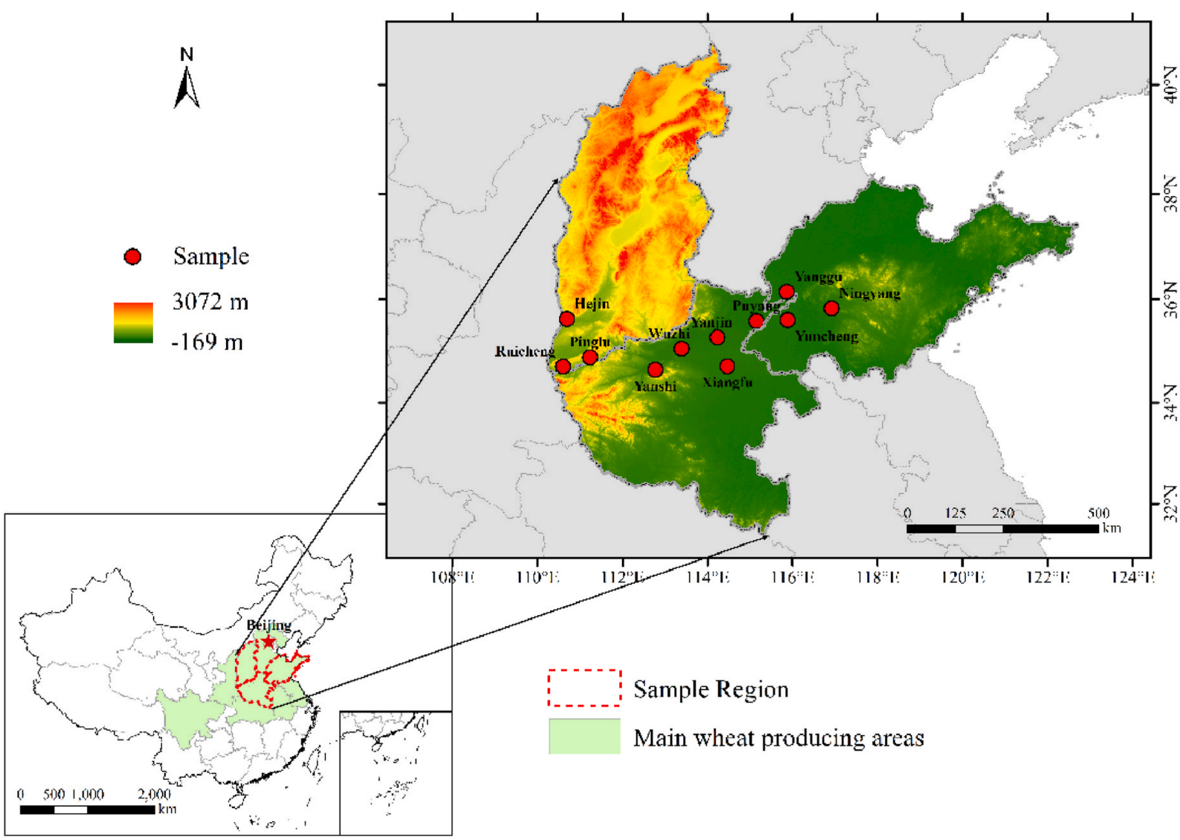


**Fig. 2.** Study region and sample distribution.

relationship between the cost OF and TE, decreasing, then increasing, eventually leveling off. There is also a non-linear relationship between the cost of OPA and TE, with a slow decline followed by a slow increase.

*3.3.2.2. Tobit model.* TE is a restricted variable between 0 and 1. Therefore, Tobit model is used to analyze the effect OF and OPA on TE. The Tobit model can be defined as:

$$TE_i = \alpha_0 + \alpha_1 x_i + \sum\nolimits_{n=1}^{N} \alpha_i C_i + \varepsilon_i \quad (4)$$

where $x$ represents OF or OPA. $C$ are the control variables shown in Table 1. $\alpha_0$、$\alpha_1$、$\alpha_i$ are the parameters to be estimated. $\varepsilon$ is the random error term. A U-shaped relationship of OF-TE and OPA-TE are considered through theoretical analysis. Therefore, the quadratic term OF or OPA respectively is added to formula (4). The estimated model can be defined as:

$$TE_i = \beta_0 + \beta_1 x_i + \beta_2 x_i^2 + \sum\nolimits_{n=1}^{N} \beta_i C_i + \varepsilon_i \quad (5)$$

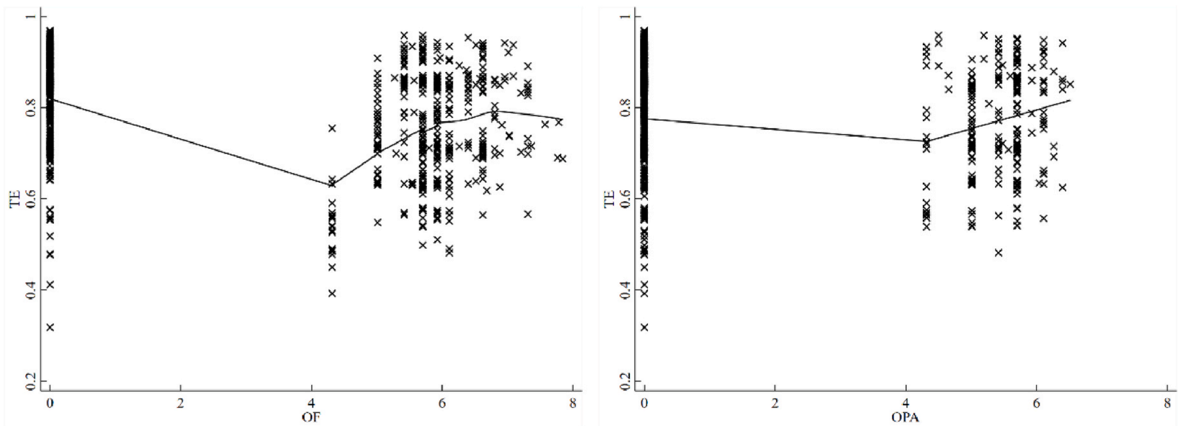


**Fig. 3.** LOWESS.

**Table 1**
Descriptive statistics of variables.

| Variables | Description | Min | Max | Mean | S.D. |
|---|---|---|---|---|---|
| Output variable | | | | | |
| Farmers' output | Wheat yield in 2020 (t/ha) | 2.250 | 11.250 | 7.197 | 1.375 |
| Input variables | | | | | |
| Labor input | Self-employment days and employment days (d/ha) | 0.569 | 300 | 44.642 | 43.909 |
| Capital input | Wheat direct input (CNY/ha) | 3000 | 23416.667 | 9786.794 | 3671.661 |
| Dependent variable | | | | | |
| TE | Calculated by SFA | 0.319 | 0.969 | 0.810 | 0.111 |
| Explanatory variables | | | | | |
| OF | Cost OF (CNY/ha) | 0 | 1950 | 185.004 | 311.618 |
| | Cost OF after logarithmically treated | 0 | 7.576 | 2.454 | 2.925 |
| OPA | Cost of OPA (CNY/ha) | 0 | 675 | 60.332 | 123.735 |
| | Cost of OPA after logarithmically treated | 0 | 6.515 | 1.274 | 2.314 |
| Instrumental variables | | | | | |
| OF at village level | Cost of other farmers in OF at the village (CNY/ha) | 0 | 668.182 | 161.402 | 171.403 |
| | Cost of other farmers in OF at the village after logarithmically treated | 0 | 6.505 | 3.539 | 2.470 |
| OPA at village level | Cost of other farmers in OPA at the village (CNY/ha) | 0 | 765 | 61.640 | 130.107 |
| | Cost of other farmers in OPA at the village after logarithmically treated | 0 | 6.640 | 2.179 | 2.130 |
| Moderator variables | | | | | |
| Plot | Wheat sown plots | 1 | 40 | 3.632 | 2.744 |
| CC | Whether wheat is grown on contiguous plots: 1 = yes, 0 = no | 0 | 1 | 0.695 | 0.460 |
| Farmers' characteristic variables | | | | | |
| Gender | Gender of the respondent: 1 = male, 0 = female | 0 | 1 | 0.789 | 0.408 |
| Age | Age of the respondent, years | 27 | 84 | 56.678 | 10.566 |
| Education level | Number of years the respondent has been in school | 0 | 18 | 8.089 | 3.164 |
| Political participation | Whether the respondent is a Communist Party member: 1 = yes, 0 = no | 0 | 1 | 0.301 | 0.459 |
| Training | Whether the respondent has been trained in agricultural technology: 1 = yes, 0 = no | 0 | 1 | 0.412 | 0.492 |
| Part-time | Whether the respondent is a part-time farmer: 1 = yes, 0 = no | 0 | 1 | 0.302 | 0.459 |
| Agricultural business variables | | | | | |
| Family labors | Number of laborers aged 18–65 in the surveyed families | 0 | 12 | 2.793 | 1.591 |
| Specialized production | Degree of specialized production = wheat sales income/total household income | 0.001 | 1 | 0.267 | 0.230 |
| Land transfer | Whether the land is transferred: 1 = yes, 0 = no | 0 | 1 | 0.347 | 0.476 |
| Cooperative | Whether the respondent joins an agricultural cooperative: 1 = yes, 0 = no | 0 | 1 | 0.230 | 0.421 |
| Regional dummy variables | | | | | |
| Shanxi | Whether the respondent is in Shanxi: 1 = yes, 0 = no | 0 | 1 | 0.303 | 0.459 |
| Shandong | Whether the respondent is in Shandong: 1 = yes, 0 = no | 0 | 1 | 0.251 | 0.434 |
| Henan | Whether the respondent is in Henan: 1 = yes, 0 = no | 0 | 1 | 0.446 | 0.497 |

where $x^2$ represents the quadratic term OF or OPA. $\beta_2$ is the parameter to be estimated for the quadratic term. However, the effect OF and OPA on TE may not be uniformly estimated due to endogeneity. There are two possible reasons for this. First, the sample self-selection bias problem, whether the farmers outsource fertilization or pesticide application is decided by the farmers themselves. Second, the problem of omitted variables. Endogeneity was controlled by the IV-Tobit model in the study. Considering OF and OPA and their quadratic terms as endogenous variables, the model can be defined after introducing instrumental variables as:

The first stage:

$$x_i = \gamma_0 + \gamma_1 IV_1 + \sum\nolimits_{n=1}^{N} \gamma_i C_i + \varepsilon_i \quad (6)$$

$$x_i^2 = \delta_0 + \delta_1 IV_2 + \sum\nolimits_{n=1}^{N} \delta_i C_i + \varepsilon_i \quad (7)$$

where $IV_1$ and $IV_2$ are instrumental variables for $x_i$ and $x_i^2$, respectively. The instrumental variable is required to satisfy the correlation and exogeneity, that is, it is related to explanatory variable and not related to the random error term.

The second stage:

$$TE_i = \theta_0 + \theta_1 \widehat{x_i} + \theta_2 \widehat{x_i}^2 + \sum_{n=1}^{N} \theta_i C_i + \varepsilon_i \quad (8)$$

where $\widehat{x_i}$ and $\widehat{x_i}^2$ are the predicted values of $x_i$ and $x_i^2$ respectively.

*3.3.2.3. Moderating effect model.* The moderating effects of plot and CC are tested in the study. The moderating effect model can be defined as:

$$TE_i = \varepsilon_0 + \varepsilon_1 x_i + \varepsilon_2 x_i^2 + \varepsilon_3 plot + \sum_{n=1}^{N} \varepsilon_i C_i + \varepsilon_i \quad (9)$$

$$TE_i = \vartheta_0 + \vartheta_1 x_i + \vartheta_2 x_i^2 + \vartheta_3 x_i \times plot + \vartheta_4 x_i^2 \times plot + \vartheta_5 plot + \sum_{n=1}^{N} \vartheta_i C_i + \varepsilon_i \quad (10)$$

$$TE_i = \rho_0 + \rho_1 x_i + \rho_2 x_i^2 + \rho_3 CC + \sum_{n=1}^{N} \rho_i C_i + \varepsilon_i \quad (11)$$

$$TE_i = \omega_0 + \omega_1 x_i + \omega_2 x_i^2 + \omega_3 x_i \times CC + \omega_4 x_i^2 \times CC + \omega_5 CC + \sum_{n=1}^{N} \omega_i C_i + \varepsilon_i \quad (12)$$

where $x \times plot$ represents the interactive items of the explanatory variables and plot $(OF \times plot, OPA \times plot)$. $x \times CC$ represents the interactive items of the explanatory variables and CC $(OP \times CC, OPA \times CC)$.

The following approach is proposed to determine the specific direction of the moderating effect. First, the inflection point is calculated and the formula can be defined as:

$$x_i^* = -\frac{\vartheta_1 + \vartheta_3 plot}{2(\vartheta_2 + \vartheta_4 plot)} \quad (13)$$

$$x_i^* = -\frac{\omega_1 + \omega_3 CC}{2(\omega_2 + \omega_4 CC)} \quad (14)$$

Second, the effect of the moderator variable on the inflection point is considered, and the partial derivative of the inflection point on the moderator variable can be calculated, and the formula is defined as:

$$\frac{\partial x_i^*}{\partial plot} = \frac{\vartheta_1 \vartheta_4 - \vartheta_2 \vartheta_3}{2(\vartheta_2 + \vartheta_4 plot)^2} \quad (15)$$

$$\frac{\partial x_i^*}{\partial CC} = \frac{\omega_1 \omega_4 - \omega_2 \omega_3}{2(\omega_2 + \omega_4 CC)^2} \quad (16)$$

If the partial derivative is more than 0, the larger the moderator variable, the larger the inflection point, and the curve shifts to the right and vice versa. Whether the partial derivative is more than 0 is determined by the numerator from formula (15) and (16).

### 3.4. Variables

#### 3.4.1. Dependent variable

The dependent variable is TE, which is measured by SFA. Its value ranges from 0 to 1. The higher the value, the higher the TE of wheat production. The input and output variables involved are shown in Table 1.

#### 3.4.2. Explanatory variables

The explanatory variables are OF and OPA, expressed by their respective cost and logarithmically treated. It is worth noting that the cost is the money spent by farmers to hire organizations or individuals to complete the fertilization or pesticide application in wheat production. Outsourced organizations or individuals conduct the work by manual or mechanical operation. Agricultural materials such as fertilizer and pesticide need to be purchased separately by farmers, which are not included in the cost. The relevant questions are "Do you outsource fertilization?" and "Do you outsource pesticide application?" If the answer is "yes", the next questions are "How many times is it outsourced?" and "How much is the per outsourcing? (Excluding agricultural materials such as fertilizer and pesticide)".

#### 3.4.3. Instrumental variables

The cost of other farmers in OF at the village is selected as the instrumental variable for OF and logarithmically treated. The quadratic term of the logarithmically treated cost of other farmers in OF at the village is selected as the instrumental variable for $OF^2$. The same goes for OPA and $OPA^2$. There are three reasons. First, farmers' behavioral decisions have conformity characteristics. Specifically, in social interactions, if a farmer's neighbors choose to outsource, this will also affect the farmer's outsourcing behavior (Bandiera and Rasul, 2006; Nakano et al., 2018). Second, the cost of other farmers' outsourcing at the village reflects the local availability of outsourcing and the market development of outsourcing to a certain extent, which affects the cost of the respondent's outsourcing. Third, the cost of other farmers' outsourcing at the village does not affect the TE of the respondent's wheat production. It is also difficult to indirectly affect the TE of the respondents' wheat production through other pathways. In conclusion, the selected instrumental variables are considered to be reasonable.

#### 3.4.4. Moderator variables

The moderator variables include plot and CC. The plot is expressed by the number of wheat sown plots. The CC is binary, which is expressed by whether wheat is sown on contiguous plots.

#### 3.4.5. Control variables

To eliminate the interference of other factors on TE, farmers' characteristic variables and agricultural business variables are included in the model as control variables (Liu et al., 2019; Ma et al., 2018; Tate et al., 2012). In addition, regional dummy variables are included in the model to control regional fixed effect. The variables involved are shown in Table 1.

## 4. Results

### 4.1. Socioeconomic characteristics of farmers

Table 2 illustrated that most respondents were male, accounting for 78.88%. The middle-aged and the elderly people were the main populations, and 28.68% of respondents were aged 50 or less. The education level of the respondents was low, and only 27.90% were in high school or above. 30.16% of the respondents were part-time. 41.16% of the respondents had been trained in agricultural technology. More than half of the families had only 3 or fewer labors. 75.93% of the families had 4 plots or less. 70.44% of the families had less than 0.67 ha arable land. The wheat sales income of the families was generally low, only 24.36% had an income of more than 15,000 CNY. 77.01% of the families did not join the agricultural cooperatives. In short, farmers were characterized by population aging, lower education level, and small-scale wheat production. There is a direct link between the amount and uniformity of FPI and wheat yield as well as flour quality. Fertilization and pesticide application need to be conducted several times in wheat production, requiring a high level of physical strength, energy, and knowledge from the farmer, which are technology-intensive stages of agricultural production. The contradiction between supply and demand prompted farmers to outsource fertilization and pesticide application.

### 4.2. Stochastic frontier approach

Results of parameter estimation by SFA were presented in Table 3. $\sigma_u$, $\sigma_v$, $\sigma^2$, $\lambda$ were significant, indicating that the farmers had technical inefficiency in the process of wheat production. The Log-likelihood value was 232, indicating that the function was well-fitted. The result

**Table 2**
Socio-economic characteristics of the respondents.

| Index | Definition | Number | Ratio (%) | Index | Definition | Number | Ratio (%) |
|---|---|---|---|---|---|---|---|
| Gender | Male | 803 | 78.88 | Number of family laborers | ≤1 | 168 | 16.50 |
| | Female | 215 | 21.12 | | (1, 3] | 499 | 49.02 |
| Age | ≤50 | 292 | 28.68 | | >3 | 351 | 34.48 |
| | (50, 65] | 485 | 47.64 | Number of plots | ≤2 | 345 | 33.89 |
| | >65 | 241 | 23.67 | | (2, 4] | 428 | 42.04 |
| Education level | Illiteracy | 43 | 4.22 | | >4 | 245 | 24.07 |
| | Primary school | 177 | 17.39 | Wheat sown area (ha) | ≤0.67 | 717 | 70.44 |
| | Junior high | 514 | 50.49 | | >0.67 | 301 | 29.57 |
| | Senior high | 256 | 25.15 | Wheat sales income (Ten thousand CNY) | ≤0.5 | 346 | 33.99 |
| | College and above | 28 | 2.75 | | (0.5, 1.5] | 424 | 41.65 |
| Part-time | Yes | 307 | 30.16 | | >1.5 | 248 | 24.36 |
| | No | 711 | 69.84 | Cooperative | Yes | 234 | 22.99 |
| Training | Yes | 419 | 41.16 | | No | 784 | 77.01 |
| | No | 599 | 58.84 | | | | |

**Table 3**
Results of parameter estimation by SFA.

| | Estimated coefficients | Standard error |
|---|---|---|
| ln $L$ | 0.015** | 0.006 |
| ln $K$ | 0.080*** | 0.018 |
| Constant | 6.546*** | 0.122 |
| $\sigma_u$ | 0.285*** | 0.012 |
| $\sigma_v$ | 0.102*** | 0.007 |
| $\sigma^2$ | 0.092*** | 0.006 |
| $\lambda$ | 2.786*** | 0.017 |
| Log likelihood | 231.535 | |
| LR | 81.18*** | |
| Observations | 1018 | |

"***", "**", "*" significant at 1%, 5%, 10% level, respectively.

of the LR indicated that it was reasonable to apply SFA to the study. The labor and capital output elasticities were 0.015 and 0.080, respectively, indicating that the wheat yield was more dependent on capital rather than labor.

The distribution of TE in wheat was shown in Fig. 4. There was a significant difference in TE for total farmers, with a maximum of 0.969, a minimum of 0.319, and a mean of 0.810. 39.78% of the farmers had a distribution of TE in the range of 0.8–0.9. In the sub-samples, the mean of TE in farmers OF was smaller than non-OF. The mean of TE in farmers of OPA was smaller than non-OPA. The mean of TE in farmers from Shanxi was smaller than Henan or Shandong.

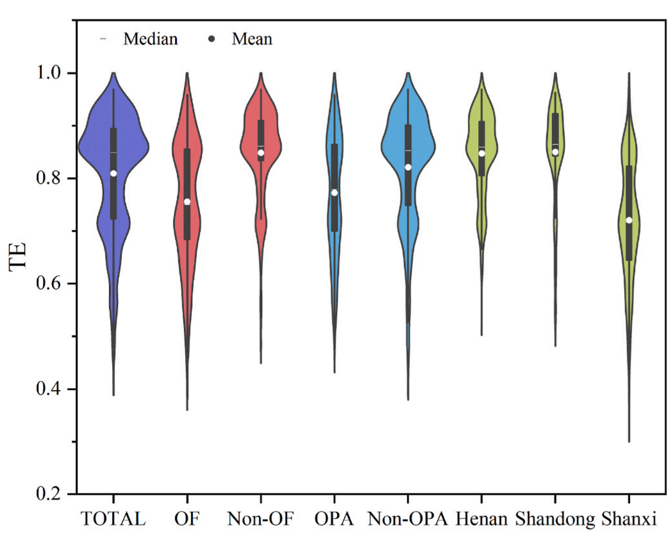


**Fig. 4.** Distribution of TE in wheat.

### 4.3. Effect OF and OPA on TE

The model was first tested for each explanatory variable before estimation to avoid the multicollinearity among the explanatory variables from affecting the empirical results. The results showed that variance inflation factor (VIF) of each explanatory variable was less than 10, indicating no strong multicollinearity among the variables. Secondly, model estimation was conducted, and the strategy was to gradually add primary and secondary terms as well as moderator variables, and the results were shown in Table 4. Finally, the IV-Tobit model was used for two-stage estimation, and the results were shown in Table 4. The results showed that OF and OPA had negative effect on TE, and $OF^2$ and $OPA^2$ had positive effect on TE. It indicated that there were non-linear relationships in the OF-TE and OPA-TE, with inflection points of 96 and 86 CNY/ha, respectively.

### 4.4. The moderating effect of the plot and CC

Table 5 showed that the plot had a moderating effect on OF-TE, and not on OPA-TE. The CC had moderating effect on OF-TE and OPA-TE. The numerator of the partial derivative of the OF-TE's inflection point on the plot was calculated to be 0.00001. The numerators of the partial derivatives of the OF-TE's and OPA-TE's inflection points on the CC were −0.00007 and −0.000195, respectively. In other words, the larger the plot, the inflection point of OF-TE shifted to the right, and the larger the CC, the more the inflection points of OF-TE and OPA-TE shifted to the left. The results were described visually by Table 6 and Table 7. The reason was that the plot weakened the positive effect OF and OPA on TE and enhanced the negative effect OF and OPA on TE. The CC did the opposite.

### 4.5. Robustness test

Group regression was employed to verify the results of the Tobit model. The inflection point was taken as the classification standard, and then divided the samples into two groups: less than the inflection point and more than the inflection point. The OLS model was used for estimation. The estimated results were shown in Table 8. The cost OF and OPA had negative effect on TE in the two groups less than the inflection point and positive effect in the two groups larger than the inflection point. It provided evidence of robustness for the results presented in the study.

The centrality treatment of variables was applied to verify the results of moderating effect model. The reason was that the centrality treatment only reduced the non-essential covariance of the variables, but not the essential covariance of the variables. It had no effect on the results of the moderating effect mode but effected on the inflection point. The estimated results were shown in Table 9. The inflection point was calculated to be consistent with the previous results, which showed that the results

**Table 4**
Effect OF and OPA on TE.

| Variables | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| OF | −0.003 (0.002) | −0.065*** (0.008) | −0.061*** (0.008) | −0.580** (0.266) | | | | |
| $OF^2$ | | 0.017*** (0.002) | 0.016*** (0.002) | 0.172** (0.079) | | | | |
| OPA | | | | | −0.009*** (0.002) | −0.061*** (0.014) | −0.054*** (0.014) | −0.042** (0.021) |
| $OPA^2$ | | | | | | 0.018*** (0.005) | 0.015*** (0.005) | 0.012* (0.007) |
| Plot | | | −0.003** (0.001) | | | | −0.003** (0.001) | |
| CC | | | 0.042*** (0.006) | | | | 0.043*** (0.006) | |
| Control variables | Controlled | Controlled | Controlled | Controlled | Controlled | Controlled | Controlled | Controlled |
| Regional dummy variable | Controlled | Controlled | Controlled | Controlled | Controlled | Controlled | Controlled | Controlled |
| Observations | 1018 | 1018 | 1018 | 1018 | 1018 | 1018 | 1018 | 1018 |

"***", "**", "*" significant at 1%, 5%, 10% level, respectively.

**Table 5**
Results of moderating effect.

| Variables | Model 9 | Model 10 | Model 11 | Model 12 |
|---|---|---|---|---|
| OF | −0.038** (0.015) | −0.114*** (0.011) | | |
| $OF^2$ | 0.011** (0.004) | 0.029*** (0.003) | | |
| OPA | | | −0.060** (0.024) | −0.116*** (0.021) |
| $OPA^2$ | | | 0.018** (0.008) | 0.030*** (0.007) |
| Plot | −0.002* (0.001) | | −0.003*** (0.001) | |
| CC | | 0.017** (0.009) | | 0.018** (0.007) |
| OF × Plot | −0.007** (0.003) | | | |
| $OF^2$ × Plot | 0.002* (0.001) | | | |
| OF × CC | | 0.091*** (0.015) | | |
| $OF^2$ × CC | | −0.023*** (0.004) | | |
| OPA × Plot | | | 0.000 (0.005) | |
| $OPA^2$ × Plot | | | −0.000 (0.002) | |
| OPA × CC | | | | 0.110*** (0.028) |
| $OPA^2$ × CC | | | | −0.027*** (0.009) |
| Control variables | Controlled | Controlled | Controlled | Controlled |
| Regional dummy variable | Controlled | Controlled | Controlled | Controlled |
| Observations | 1018 | 1018 | 1018 | 1018 |

"***", "**", "*" significant at 1%, 5%, 10% level, respectively.

**Table 6**
Curve changes under different scenarios (OF) (Unit: CNY/ha).

| Scenario | Curve slope | | | | | | |
|---|---|---|---|---|---|---|---|
| | $<NIP_1$ | $NIP_1$ | $(NIP_1, 96)$ | 96 | $(96, NIP_2)$ | $NIP_2$ | $>NIP_2$ |
| Baseline | – | – | – | 0 | + | + | + |
| Plot | – | – | – | – | – | 0 | + |
| CC | – | 0 | + | + | + | + | + |

New inflection point (NIP).

**Table 7**
Curve changes under different scenarios (OPA) (Unit: CNY/ha).

| Scenario | Curve slope | | | | | | |
|---|---|---|---|---|---|---|---|
| | $<NIP_3$ | $NIP_3$ | $(NIP_3, 86)$ | 86 | $(86, NIP_4)$ | $NIP_4$ | $>NIP_4$ |
| Baseline | – | – | – | 0 | + | + | + |
| CC | – | 0 | + | + | + | + | + |

New inflection point (NIP).

**Table 8**
Robustness test based on group regression.

| | Model 13 | Model 14 | Model 15 | Model 16 |
|---|---|---|---|---|
| | ≤96 CNY/ha | >96 CNY/ha | ≤86 CNY/ha | >86 CNY/ha |
| OF | −0.119*** (0.011) | 0.031*** (0.008) | | |
| OPA | | | −0.053*** (0.012) | 0.022* (0.013) |
| Control variables | Controlled | Controlled | Controlled | Controlled |
| Regional dummy variable | Controlled | Controlled | Controlled | Controlled |
| Observations | 614 | 404 | 797 | 221 |
| LR | 439.65 | 154.62 | 464.31 | 148.75 |
| Pseudo $R^2$ | −0.425 | −0.236 | −0.369 | −0.427 |

"***", "**", "*" significant at 1%, 5%, 10% level, respectively.

of the moderating effect model were robust.

### 4.6. Heterogeneity test

The sown area is one of the characteristics that distinguish the type of farmers. The average sown area of wheat was taken as a classification standard, and then the samples were divided into two groups. The estimated results were shown in Table 10. There were significant non-linear relationships between the cost OF and TE for different scale of farmers. Larger-than-average groups had higher inflection points. There was a significant non-linear relationship between the cost of OPA and TE for farmers with less than average. There was no significant relationship between the cost of OPA and TE for farmers with above-average TE.

## 5. Discussions and implications

Facing ecological pressure and resource scarcity, it is crucial to ensure food security. From the perspective of sustainable and green development, it is undesirable to achieve increased food production by relying solely on the FPI. FPI reduction and efficiency improvement

**Table 9**
Robustness test based on centrality treatment of variables.

| Variables | Model 17 | Model 18 | Model 19 | Model 20 |
|---|---|---|---|---|
| OF | −0.063*** | −0.050*** | | |
| | (0.008) | (0.008) | | |
| $OF^2$ | 0.017*** | 0.013*** | | |
| | (0.002) | (0.002) | | |
| OPA | | | −0.060*** | −0.040*** |
| | | | (0.015) | (0.014) |
| $OPA^2$ | | | 0.017*** | 0.011** |
| | | | (0.005) | (0.005) |
| Plot | −0.004*** | | −0.004*** | |
| | (0.001) | | (0.001) | |
| CC | | 0.039*** | | 0.041*** |
| | | (0.006) | | (0.006) |
| OF × Plot | −0.007** | | | |
| | (0.003) | | | |
| $OF^2$ × Plot | 0.002* | | | |
| | (0.001) | | | |
| OF × CC | | 0.091*** | | |
| | | (0.015) | | |
| $OF^2$ × CC | | −0.023*** | | |
| | | (0.004) | | |
| OPA × Plot | | | 0.000 | |
| | | | (0.005) | |
| $OPA^2$ × Plot | | | −0.000 | |
| | | | (0.002) | |
| OPA × CC | | | | 0.110*** |
| | | | | (0.028) |
| $OPA^2$ × CC | | | | −0.027*** |
| | | | | (0.009) |
| Control variables | Controlled | Controlled | Controlled | Controlled |
| Regional dummy variable | Controlled | Controlled | Controlled | Controlled |
| Observations | 1018 | 1018 | 1018 | 1018 |

"***", "**", "*" significant at 1%, 5%, 10% level, respectively.

**Table 10**
Effect OF and OPA on TE: Scale difference.

| Variables | Below mean | | Above mean | |
|---|---|---|---|---|
| | Model 21 | Model 22 | Model 23 | Model 24 |
| OF | −0.065*** | | −0.033** | |
| | (0.008) | | (0.016) | |
| $OF^2$ | 0.018*** | | 0.008* | |
| | (0.002) | | (0.004) | |
| OPA | | −0.067*** | | −0.003 |
| | | (0.016) | | (0.024) |
| $OPA^2$ | | 0.020*** | | 0.000 |
| | | (0.006) | | (0.008) |
| **Inflection point** | **91CNY/ha** | **84CNY/ha** | **120CNY/ha** | **–** |
| Plot | −0.005** | −0.005** | −0.002* | −0.002* |
| | (0.002) | (0.002) | (0.001) | (0.001) |
| CC | 0.043*** | 0.045*** | 0.029** | 0.028* |
| | (0.007) | (0.007) | (0.014) | (0.015) |
| Control variables | Controlled | Controlled | Controlled | Controlled |
| Regional dummy variable | Controlled | Controlled | Controlled | Controlled |
| Observations | 837 | 837 | 181 | 181 |

"***", "**", "*" significant at 1%, 5%, 10% level, respectively.

were emphasized in the 2023 Central No. 1 document.[8] As environmental-friendly agricultural production practices, OF and OPA can improve the utilization efficiency of fertilizer and pesticide and reduce the application of fertilizer and pesticide (Guenter et al., 2012; Klasen et al., 2016; Yan et al., 2021; Yang et al., 2022; Zhang and Luo, 2020). However, the effect OF and OPA on TE needs to be tested. The paper reveals the effect mechanisms OF and OPA on TE and makes suggestions for the promotion OF and OPA and the improvement of TE.

### 5.1. What can we know from the non-linear relationship?

Agricultural production outsourcing plays an important role in promoting agricultural stable development. However, it still faces challenges such as weak capacity and low quality.[9] The study further clarifies the effect mechanism OF and OPA on TE and provides theoretical support for further promotion OF and OPA and ensuring national food security.

Firstly, reducing the negative principal-agent effect is one of the keys to promoting OF and OPA and improving TE. Relevant policies should be made to regulate the behavior of outsourcing providers and improve their outsourcing quality. On the one hand, it is necessary to formulate standards for outsourcing. Outsourcing quality significantly affects farmers' willingness and behavior. The outsourcing market is imperfect, and the proportion of professional outsourcing providers is relatively low. Standardized operational procedures have not yet been formed. It is not helpful for farmers to assess the quality of outsourcing. On the other hand, the outsourcing insurance market should be developed. In times of asymmetric information, the purchase of insurance is an effective way for farmers to avoid the opportunistic behavior of outsourcing providers.

Secondly, farmers should choose the appropriate times of outsourcing with full consideration of household capital and labor under the constraints of local outsourcing prices. The study results showed that TE increased as the cost OF and OPA increased after the inflection point. The fertilization and pesticide application are conducted several times in wheat production, and the cost OF and OPA is the multiplication of the outsourced times and the unit price. The providers determine the price in outsourcing, and farmers cannot intervene (Zhan et al., 2016). If the price is too high for farmers to afford, they may tend to conduct the fertilization and pesticide application themselves. Increasing the frequency OF and OPA will increase the financial burden on farmers. However, it will further leverage the positive effect OF and OPA to improve TE. It will also reduce the intensity of farmers' agricultural work and avoid damage to farmers' health caused by improper FPI. If farmers use the time saved in part-time jobs, they can cover part of the cost OF and OPA. The survey shows that the prices OF and OPA are around 450 and 120 CNY/ha respectively. Farmers mostly outsource fertilization once and pesticide application twice. It is in the promotion OF and OPA to TE. With an average sown area of 1.21 ha for the sample, the total cost would be about 837 CNY. Farmers can earn about 150 CNY/day by part-time jobs (Mi et al., 2020). It takes six days to offset the cost. If a farmer does part-time jobs 30 days a year, it can be estimated that 35.95 million rural households in the study area will increase by 129.4 billion CNY. It will drive regional economic development. Consequently, policy propaganda and training for farmers should be enhanced, which can improve farmers' outsourcing knowledge. Farmers can choose the appropriate outsourcing times to improve TE.

### 5.2. What can we know from the moderating effect of the plot and CC?

The establishment of the household contract responsibility system has stimulated farmers' enthusiasm for production, but has also indirectly caused land fragmentation. The large-scale sown area was only 28.6% of the actual sown area, and 210 million households operated less than 0.667 ha of arable land in 2016[10]. Currently, land fragmentation has become one of the major obstacles limiting the high-quality development of agriculture. It is not favorable for mechanical production and field management. So, it may lead to higher production cost and lower TE due to increased fuel consumption and mechanical loss. For this

[8] http://www.gov.cn/zhengce/2023-02/13/content_5741370.htm.

[9] http://www.gov.cn/zhengce/zhengceku/2021-07/16/content_5625383.htm.

[10] http://www.stats.gov.cn/tjsj/tjgb/nypcgb/qgnypcgb/.

reason, the "China High Standard Farmland Construction Plan" proposes to construction concentrated and contiguous high-standard farmland of 71.7 million ha by 2025. The CC can take advantage of the scale production and improve TE. The results of the study support the above policies.

After the construction of high-standard farmland, grain yield increases by 10–20%, with a cost reduction of 7500 CNY/ha in production.[11] Shanxi, Shandong, and Henan are the main producing provinces of high-quality wheat. Farmland infrastructure is low, and there is an urgent need for renovation and upgrading. A major problem with the current high-standard farmland is that the traditional mode of production is still used, and does not play a fully effective role in promoting the agricultural green development. Literature showed that OF and OPA were environmental-friendly agricultural production practices. They can improve the utilization efficiency of fertilizer and pesticide and reduce the application of fertilizer and pesticide (Guenter et al., 2012; Klasen et al., 2016; Yan et al., 2021; Yang et al., 2022; Zhang and Luo, 2020). The government should strengthen farmers' ability to collective action by cropping the same grain in contiguous plots. It can induce specialization horizontally and leverage scale economy. The survey shows that the means of wheat yield are 7.5 and 6.6 t/ha for contiguous and non-contiguous cropping, respectively. If wheat is grown on the completed concentrated and contiguous high-standard farmland, the yield is about 8.6 t/ha with a 15% increase. It also enables the positive effect OF and OPA to outweigh the negative effect at a lower cost level. At the same time, it releases the labor force and realizes the optimal resources allocation. Consequently, the government should accelerate the construction of high-standard farmland, strengthen farmers' ability in collective action, promote concentrated and contiguous wheat production. It can contribute to improve scale efficiency, and mitigate the negative effect OF and OPA on TE due to land fragmentation.

### *5.3. Why to promote OF and OPA to different groups?*

The number of large-scale farmers was 3.98 million, accounting for only 1.92% of Chinese farmers in 2016.[12] Smallholder management may remain the main form of agricultural production in the future. It is not favorable to the agricultural modernization. For this reason, while developing moderate scale business, strengthening the development of outsourcing is an essential pathway to improve the agricultural competitiveness of smallholder farmers.[13] The results of the heterogeneity test provide evidence for the promotion of outsourcing.

For large-scale farmers, it is less constrained to adopt agricultural green production practices. Outsourcing is not the only way for them to reduce FPI and improve the TE of wheat production. They can make a rational choice between purchasing machinery and outsourcing based on the criterion of maximizing family revenue. Compared to large-scale farmers, small-scale farmers maybe afford higher cost to purchase machinery and introduce technology. In the context of rising opportunity cost of farming and the aging and feminization of the rural labor force, small-scale farmers have a greater positive effect on outsourcing. Consequently, the government should guide farmers with different endowments to purchase OF and OPA reasonably and provide them relevant subsidies to reduce agricultural production cost, so that they can effectively connect with agricultural modernization.

## 6. Conclusions

FPI provided the possibility for sustainable increase in wheat production. However, it has caused environmental problems and agricultural product quality decline. Agricultural production outsourcing was introduced to address the challenges in promoting agricultural green production practices. Under the combined effect of principal-agent, labor substitution, and technology-inducing, it is worth discussing whether OF and OPA can improve TE. Literature was controversial regarding the results of the effect OF and OPA on TE, and less attention had been paid to the effect of the plot and CC as important moderators. Therefore, the study enriches the literature. The study first validated the effect OF and OPA on TE, and then further tested the moderating effect of the plot and CC. According to the results, the cost OF and OPA had a negative and then positive impact on TE. The plot had moderating effect on OF-TE, shifting its inflection point to the right. The CC had moderating effect on OF-TE and OPA-TE, shifting their inflection points to the left. Smaller-than-average groups were more sensitive to the increase in the cost of the OF and OPA. Therefore, it is necessary to formulate standards for fertilization and pesticide application and to develop an insurance market. Farmers can also maximize the positive effect of outsourcing by choosing the appropriate times. More government training for farmers is needed. The construction of high-standard farmland and CC can mitigate the negative effect OF and OPA on TE due to land fragmentation. Farmers with different endowments should be guided to purchase OF and OPA reasonably, and government subsidies should be provided.

However, the limitations of the study should also be recognized. The sample used in the study is only for wheat, although to improve the sample's representativeness, the main wheat-producing regions were selected in China. A larger sample with broader spatial and temporal data can be used to further support the findings. Future studies can be conducted on the effect OF and OPA on the TE of other grain.

## CRediT authorship contribution statement

**Yingnan Zhang:** conceptualization, questionnaire development, methodology, data curation, software, formal analyses, writing original draft, visualization, writing review and editing, validation. **Yanshu Yin:** data curation, writing-review and editing. **Fuduo Li:** co-supervision, project administration, writing-review, editing and validation. **Wenjing Duan:** data curation, writing-review and editing. **Ke Xu:** data curation, writing-review and editing. **Changbin Yin:** supervision, investigation, writing original draft, resources, project administration, Funding acquisition.

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## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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[11] https://www.ndrc.gov.cn/fggz/fzzlgh/gjjzxgh/202111/P020211102598713060217.pdf.

[12] http://www.stats.gov.cn/tjsj/tjgb/nypcgb/qgnypcgb/.

[13] http://www.gov.cn/zhengce/2019-02/21/content_5367487.htm.

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