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# The Impact of Changes in Rural Family Structure on Agricultural Productivity and Efficiency: Evidence from Rice Farmers in China

**Donghui Song, Fengbo Chen * and Xi Ouyang**

College of Economics and Management, South China Agricultural University, Guangzhou 510642, China; dhsong@stu.scau.edu.cn (D.S.); ouyangxi@stu.scau.edu.cn (X.O.)
* Correspondence: cfb@scau.edu.cn

**Abstract:** Over the past three decades, China has shifted from a relatively immobile society to one where rural migrant workers are dispersed throughout urban areas, resulting in significant changes in rural family structure. Previous studies have tended to approach migrant workers as homogeneous groups within families. In contrast, our attention turns to the diversity among individuals and the complex interactions within families. Based on a survey of rice farmers in five provinces of China, this study aims to explore the heterogeneous impact of changes in rural family structure on the single-factor (i.e., land, labor, and capital) productivity and technical efficiency (TE) of rice production. Methodologically, we calculated the productivity indicator through the Cobb–Douglas production function. Following this, a one-step stochastic frontier approach (SFA) was employed to assess the production frontier and estimate inefficiency. To address self-selection bias in family migration behavior, we applied the propensity score matching method (PSM). The results reveal that significant outcomes are observed only with certain types of changes in rural family structure. The production decisions of rural families are influenced by the migration regions of their family members. Compared to non-migrating families (NM), families with couples' joint migration outside the province show higher single-factor productivity and TE. We used multiple approaches to examine the results and came to similar conclusions. Therefore, enhancing social security measures and employment opportunities for migrant workers, with specific attention to supporting migrant couples, can have a positive impact on sustainable urban and rural development, as well as food security.

**Keywords:** rural–urban migration; migration regions; single-factor productivity; technical efficiency

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## 1. Introduction

Since 1978, the household contract responsibility system has been implemented in China's rural areas, providing farmers with the rights to manage and utilize land. This approach has successfully heightened enthusiasm for agricultural production, promoting long-term investments in land management and enhancement. However, due to China's small-scale peasant economy, this system has led to a significant surplus of labor in rural areas. In order to make effective use of agricultural leisure time and increase household income, some farmers have migrated to urban areas in search of off-farm employment opportunities. Since then, rural families in China have experienced structural changes spanning over 30 years.

The proportion of off-farm work participants within the overall farm labor force has seen a substantial increase, rising from 9.3% in 1978 to 74.9% in 2015 [1]. According to the National Bureau of Statistics of China, the total number of migrant workers reached 277.47 million in 2015 [2]. Among them, 60.8% were non-local migrant workers, 45.9% engaged in cross-province migration, and over half of these migrant workers were married. Nearly 90% of married migrants from the "new generation" actively chose to migrate as couples in 2015 [3]. The trend of joint migration among couples is experiencing a steady rise, emerging as the dominant pattern in migration [4].

The large-scale rural–urban migration (RUM) in China has raised concerns among scholars regarding the nation's food security [5]. However, despite the decline in the agricultural labor force in China, the area and yield of cereal crops continuously increased for the 12 consecutive years from 2003 to 2015. Notably, the area of rice cultivation grew by 16.13%, and the yield of rice production increased by 32.05% during this period. These trends indicate that, contrary to expectations, RUM has not negatively impacted China's food security. Instead, it has played a role in enhancing agricultural productivity and efficiency.

Studies on the relationship between RUM and agricultural productivity and efficiency offer mixed and inconclusive findings. On the one hand, due to the negative lost-labor effect, RUM results in a decline in the quality [6] and motivation [7] of farm labor, as well as a reduction in agricultural productivity and efficiency [8]. In certain instances, the burden of RUM may even push farmers to consider abandoning their agricultural activities [9]. On the other hand, due to the positive effect of income transfers from migrants, RUM leads to an increase in total household income [10] and loosens household budget constraints on agricultural production [11]. Farmers possess the capability to alleviate the effects of labor loss by increasing farm inputs, resulting in an improvement in agricultural productivity and efficiency [12]. Additionally, several studies argue that RUM does not have a significant impact on agricultural productivity and efficiency [5,13].

The field of development economics has introduced various theories regarding the impact of RUM on farm production. According to Lewis' dual economy model, farm production remains largely unaffected by RUM due to the presence of surplus farm labor with zero marginal productivity in agriculture, a characteristic of developing countries [14,15]. Similarly, the agricultural household model (AHM) suggests that production decisions of farmers are independent of consumption and off-farm employment [16]. The new economics of labor migration (NELM) postulates that, while productive labor lost to non-farm sectors reduces farm production in the short run, migrant remittances home can compensate for the loss by financing new farm technology [17]. However, existing theories typically treat the intra-family labor force as a homogeneous group, ignoring the diversity among individuals and the complex interactions within families [18].

NELM emphasizes that migration decisions are strategic choices made at the household level, rather than independent individual decisions [17]. Unfortunately, most research methods for analyzing RUM decisions continue to focus on individual decision models [4]. The structure of families, along with its variations across different regions and time periods, remains under-researched. This study aims to address this gap by specifically examining the heterogeneous effects of changes in rural family structure on agricultural productivity and efficiency, with a particular emphasis on the interdependent relationship between husband and wife. By investigating the different types of dynamics that emerge when husband and wife engage in migration activities, our research provides insights into the distinct roles, contributions, and interactions of husband and wife. This approach recognizes the importance of considering family structure changes and the division of labor within rural families, which can significantly impact agricultural outcomes.

In recent years, the differences in intra-family labor dynamics have received increasing attention. Some studies focus on the migration decisions of household heads, who dominate household decision-making [19,20]. The off-farm work of household heads has been found to have a positive and statistically significant effect on farm inputs, such as fertilizers and pesticides [20]. There is also research that considers gender differences within the labor force. For example, husbands and wives hold different attitudes in decisions about labor distribution, childbirth, and internal care within families [21]. Few studies recognize the empirical importance of examining couples' joint migration [4]. Households in which only the husband migrates are more likely to rent in land, whereas those in which only the wife migrates are less likely to do so; couples who jointly migrate are more likely to rent out land [22]. Unlike previous studies, this study explores the heterogeneous effects of changes in rural family structure on the productivity and efficiency of rice farmers. Couples' joint migration (both the husband and wife are migrant workers) and split migration (one of the spouses migrates and the other stays at home) are used to characterize changes in family structure. Taking non-migrating families as a reference group, we find that there are large differences in farm efficiency among different family structures. Notably, the concept of an extended family is prevalent in developing countries, especially in China. For thousands of years, couples, the elderly, and children have resided together in China, shaping daily life and sharing living spaces. When couples migrate to urban centers for off-farm work, elderly family members often stay behind in the rural hometowns to manage the farms. Extensive studies have explored these issues [23–25].

The choice of location for migrant workers is a crucial aspect of migration decision-making, which is often disregarded in the existing literature. While extended migration distances may lead to a higher income, they also come with increased costs related to time, transportation, and information [26]. In general, local migrant workers can strike a balance between off-farm work and farm production. Long-distance migrants need a wage premium to overcome the costs associated with moving between culturally diverse regions [27]. In this study, we examine the regional choices made by migrant workers, specifically focusing on whether they choose to migrate inside or outside of the province. The findings reveal that rural families with different migration distances tend to adopt distinct production strategies.

Our study contributes to several branches of the literature. First, it complements the literature on RUM. Over the years, migration research has primarily focused on individuals' movement to and settlement processes in urban areas. Our attention turns to the individual differences and the division of labor force within families. By exploring the heterogeneous effects of changes in family structure on the production decisions of farmers, our study highlights the significance of couples' joint migration for government policies. Second, our study supports the research on migration region heterogeneity and distance heterogeneity. Our empirical evidence shows that there are differences in the economic consequences between migration inside the province and migration outside the province. Third, previous studies usually used "unit land output" or "unit land output value" (i.e., land productivity) to discuss the relationship between RUM and farms' efficiency [5]. The richness of the dataset allows us to pinpoint both single-factor productivity indicators (i.e., land productivity, labor productivity, and capital productivity) and technical efficiency. We argue that different efficiency indicators carry unique policy implications.

The remainder of this paper is organized as follows. Section 2 describes the research methodology. The data and variables are presented in Section 3. Section 4 presents the empirical results. Section 5 contains the discussions; Section 6 comprises the conclusions and suggestions.

## 2. Research Methodology

### 2.1. Single-Factor Productivity

Following Fan (1991) [28], Lin (1992) [29], and Zhang and Carter (1997) [30], this study adopted the Cobb–Douglas production function. This equation is specified as follows:

$$Y_i = A_0 K_i^{\alpha_K} L_i^{\alpha_L} S_i^{\alpha_S} e_i^{\varepsilon} \tag{1}$$

The value of rice output is used to measure the productivity and efficiency of rice farmers [31,32]. $Y_i$ represents the value of rice output for farmer $i$; $K_i$ represents the capital of rice inputs for farmer $i$, such as seeds, fertilizers, pesticides, service, energy and other inputs; $L_i$ represents the amount of labor time dedicated to rice production for farmer $i$; $S_i$ is the sown area of rice production for farmer $i$; $\alpha_K$, $\alpha_L$, and $\alpha_S$ are the output elasticity for each key inputs, respectively; and $\varepsilon$ is the random disturbance term. According to the Cobb–Douglas production function, the single-factor productivity can be expressed as follows:

$$productivity_{ik} = Y_i / k_i \tag{2}$$

where $productivity_{ik}$ represents the single-factor productivity of the three farm inputs $k$ of farmer $i$, and $k$ indicates the input factors, namely land $S$, labor $L$, and capital $K$.

Land productivity can be quantified as the rice output value per unit of land [33,34], denoted by $Land\ productivity = Y/S$.

Labor productivity can be measured as the rice output value per labor day [34,35], represented as $Labor\ productivity = Y/L$.

Capital productivity, an essential indicator for evaluating output–input ratios in farm production, is defined in this paper as the ratio of the rice output value to the capital of rice inputs [34], represented as $Capital\ productivity = Y/K$.

### 2.2. One-Step Stochastic Frontier Approach

TE is a measure of how effectively a producer utilizes its resources to generate output. It quantifies the degree to which a producer deviates from achieving the maximum output possible using the currently available technology. TE is typically defined as the ratio of the actual output to the maximum output that could be produced using the same inputs under the current technological conditions. The SFA is frequently used to estimate TE by decomposing the error term of the production function into two parts, namely the random and the non-random parts [36–38].

According to the estimation process, the SFA can be divided into the "one-step" and "two-step" methods. The "two-step" method refers to estimating the stochastic frontier production function to obtain TE, and then using the obtained TE index to regress the relevant variables. The "one-step" refers to the estimation of TE by expressing the technical inefficiency index as a function of a group of exogenous variables and random perturbation terms in the random frontier production function. Research indicates that "one-step" SFA estimation avoids biased outcomes arising from the different statistical distribution assumptions in the "two-step" estimation [39]. Furthermore, through Monte Carlo tests, Wang (2002) [40] demonstrated that the "one-step" SFA outperforms the "two-step" SFA.

This study adopted the one-step SFA to estimate TE [32,37]. The random error term in the Cobb–Douglas production function can be decomposed as $\varepsilon_i = v_i - u_i$ [41,42]. Consequently, the stochastic frontier production function can be expressed as follows:

$$Y_i = A_0 K_i^{\alpha_K} L_i^{\alpha_L} S_i^{\alpha_S} exp\ (\nu_i - \mu_i) \tag{3}$$

$v_i \sim N\left(0, \sigma_v^2\right)$ is used to measure the error caused by uncontrollable random factors and $\mu_i \sim N^+\ (\overline{u},\ \sigma_u^2)$ follows truncated distribution and captures the technical inefficiency term of farmer $i$. Following Liu et al. (2019) [26] and Aljohani and Chidmi (2024) [42], the TE can be expressed as follows:

$$\begin{gathered} TE_i = E\left(Y_i \middle| u_i, Z_{\mathrm{ij}}\right)/E\left(Y_i \middle| u_i = 0, Z_{ij}\right) = exp\ (-u_i) \\ u_i = -ln(TE_i) \end{gathered} \tag{4}$$

where $Z_{ij}$ represents a vector of inputs in the production frontier model, which refers to land $S$, labor $L$, and capital $K$. If $u_i = 0$, then $TE_i = 1$, and the farmer reaches the optimal technical efficiency level and operation at the production frontier. When $u_i > 0$, $TE_i \in (0,1)$, farmer $i$ is technically inefficient and operates below the production frontier.

$$\gamma = \sigma_u^2\ /\ \sigma^2,\ \sigma^2 = \sigma_v^2\ + \sigma_u^2\ \left(0 \leq\ \gamma\ \leq 1\right) \tag{5}$$

where $\gamma$ reflects the proportion of technical inefficiency terms in the total composite variance. $\sigma^2$ represents the total composite variance; $\sigma_u^2$ represents the technical inefficiency terms; and $\sigma_v^2$ represents the noise term. The closer $\gamma$ is to 1, the more it indicates that the error primarily comes from the technical inefficiency term $u_i$, making the adoption of the SFA model more appropriate.

### 2.3. Empirical Strategy

#### 2.3.1. Model for the Impact of Changes in Rural Family Structure on Single-Factor Productivity

To examine the impact of changes in rural family structure on single-factor productivity, this study referred to the empirical analysis model of Feng et al. (2010) [5], and set up the estimation model as follows:

$$Productivity_{ik} = a_{0k} + a_{1k}Stru_i + a_{2k}X_i + year_f + province_f + \varepsilon_{ik} \quad (6)$$

where $Productivity_{ik}$ represents the $k$th single factor productivity of family $i$; $k$ represents land $S$, labor $L$, and capital $K$; $Stru_i$ represents the structure of family $i$; $X_i$ is a vector of the control variables listed in Table 1; $year_f$ and $province_f$ represent the year and province dummy variables, respectively; $a_{0k}$ is a constant term; $a_{1k}$ and $a_{2k}$ are the coefficients to be estimated and $\varepsilon_{ik}$ is a random error term.

**Table 1.** Definition and descriptive statistics of variables (N = 1585).

| Variable Types | Variable Names | Variable Definitions | Mean | SD |
|---|---|---|---|---|
| **Dependent Variables: Productivity and Efficiency** | | | | |
| Single-factor productivity | Land productivity | Rice output value per unit of land (EUR/ha) | 2456.22 | 649.09 |
| | Labor productivity | Rice output value per labor day (EUR/day) | 29.44 | 89.57 |
| | Capital productivity | Ratio of the rice output value to the capital of rice inputs | 2.98 | 11.06 |
| Technical efficiency | TE | TE score (calculated by one-step SFA) | 0.86 | 0.11 |
| **Independent Variables: Changes in Rural Family Structure (ref. Non-migrating families)** | | | | |
| Couples' joint migration | CJMI | Couples' joint migration inside the province | 0.11 | 0.31 |
| | CJMO | Couples' joint migration outside the province | 0.10 | 0.29 |
| Couples' split migration | OSMI | One spouse's migration inside the province | 0.10 | 0.30 |
| | OSMO | One spouse's migration outside the province | 0.05 | 0.22 |
| Others' migration | TOMI | Others' migration inside the province | 0.15 | 0.36 |
| | TOMO | Others' migration outside the province | 0.07 | 0.25 |
| **Control Variables** | | | | |
| Farmer characteristics | Farm laborers | Number of farm laborers | 2.08 | 0.98 |
| | Age | Average ages of farm laborers (years) | 55.49 | 9.90 |
| | Education | Average school years of farm laborers (years) | 6.25 | 2.87 |
| | Health | Average health status of farm laborers (1 = worse, 2 = general, 3 = good) | 2.56 | 0.56 |
| Family characteristics | Size | Number of family members | 5.13 | 2.18 |
| | Male | Share of males in total family members (%) | 0.55 | 0.14 |
| | Cadres | Family member is a village cadre = 1, otherwise = 0 | 0.11 | 0.31 |
| | Migration of householder | Householder engaged in migration = 1, otherwise = 0 | 0.01 | 0.09 |
| | Off-farm income | Share of off-farm income in total income (%) | 0.67 | 0.37 |
| | Dependency | Share of people under 16 and above 60 years old in total family members (%) | 0.40 | 0.29 |
| Farm characteristics | Cultivated area | Cultivated area used for rice production (ha) | 1.61 | 22.76 |
| | Fragmentation | The ratio of cultivated area to the number of farmland plots | 0.31 | 4.45 |
| | Commute | Commuting time from home to farmland (minute) | 12.14 | 9 |
| | Distance | The nearest distance from farmland to market (km) | 3.37 | 2.66 |

#### 2.3.2. Model for the Impact of Changes in Rural Family Structure on TE

The one-step SFA was employed to assess the production frontier and estimate inefficiency. The estimated model of the one-step stochastic frontier production function is as follows:

$$\begin{gathered} lny_i = \beta_0 + \sum_k \beta_k lnZ_{ik} + v_i - u_i \\ u_i = \gamma_0 + \gamma_1 Stru_i + \gamma_2 D_i + year_f + province_f + \omega_i \\ v_i \sim\ N\left(0, \sigma_v^2\right), \mu_i \sim\ N^+\left(\overline{u},\ \sigma_u^2\right) \end{gathered} \tag{7}$$

where $lny_i$ is the logarithm of the value of rice output of family $i$; $Z_{ik}$ represents the $k$th farm inputs of family $i$, including land $S$, labor $L$, and capital $K$; $D_i$ represents a series of exogenous variables that may affect TE; $\beta_0$ and $\gamma_0$ are constant terms; $\beta_k$, $\gamma_1$, and $\gamma_2$ are the coefficients to be estimated; and $\omega_i$ is the random error term. The other variables and parameters are defined as those in Equation (6). The stochastic frontier production function parameter determined by Equation (7) was estimated using the maximum likelihood estimation (MLE) method.

#### 2.3.3. Propensity Score Matching (PSM) Method

Since the migration behavior of families is a self-selecting process, the probability of an observer entering our treatment group is non-random and endogenous in our model, meaning that there is a selection bias. To address this selection bias, Rosenbaum and Rubin (1983) [43] suggested a counterfactual framework known as the propensity score matching method. This method matches observable variables between the treatment and control groups based on propensity scores. Following Rosenbaum and Rubin (1983) [43], the PSM is modeled as:

$$p(X) = p_r(D = 1|X) = E(D|X) \tag{8}$$

We assume $D$ is a binary treatment variable that indicates whether families receive treatment. In this study, we took NM as the control group $(D = 0)$. The changes in structures of families were divided into 6 groups, and each family migration structure was assigned to the treatment group $(D = 1)$. $X$ is a vector of pre-treatment characteristics.

The average treatment effect on the treated (ATT) is specified as:

$$ATT = E(Y_1 - Y_0|D = 1) = E(Y_1|D = 1) - E(Y_0|D = 1) \tag{9}$$

where $ATT$ is the average treatment effect of the treated; $Y$ represents the outcome variables; $Y_1$ represents the outcome variables of the treatment group and $Y_0$ represents the outcome variables of the control group.

Then, the treatment effects based on the propensity score is estimated as follows:

$$ATT = E(Y_1|D = 1, p(X)) - E(Y_0|D = 0, p(X)) \tag{10}$$

This study used the nearest neighbor matching to match the treated and control observations by following Mayen et al. (2010) [44] and Mazhar et al. (2022) [45]. The nearest neighbor matching procedure involves matching the treatment group and NM with the closest propensity score as matching partners. We generated as many control variables that can potentially affect the productivity and efficiency of rice farmers as we could to estimate the propensity score.

## 3. Data and Variables

### *3.1. Data*

We focused on five provinces in the middle and lower reaches of the Yangtze River in China, namely Guangdong, Jiangxi, Anhui, Hubei, and Hunan. These five provinces are representative for the study of rice production in China. Firstly, they are located in different parts of China: Guangdong in the south, Jiangxi in the southeast, Anhui in the east, Hunan in the south-central, and Hubei in the central region. Secondly, these provinces provide a variety of natural environments that support successful rice cultivation. For instance, Guangdong boasts a subtropical climate with warm, humid conditions and abundant rainfall. Jiangxi stands out for its varied farming practices and rich agricultural history. Anhui, situated along the Huaihe and Yangtze River Basins, benefits from abundant water resources that facilitate irrigation and rice farming. Hunan is renowned as one of the country's largest rice-producing regions, known for its extensive rice fields and high yields. Hubei features diverse geography, including plains, hills, and mountains. In short, these regions are pivotal for rice cultivation in China, contributing significantly to the nation's rice production. According to the China Statistical Yearbook 2020, these provinces collectively contributed 44% of China's total national rice production and accounted for 46% of China's total rice sown area [46].

In addition to the agricultural significance, these regions also experience substantial population mobility. According to the data from the China Population Census Yearbook 2020 [47], Guangdong had a floating population of more than 50 million, making it the largest migrant province in China. Jiangxi, Anhui, Hubei, and Hunan had floating populations of 13.52 million, 13.87 million, 12.76 million, and 17.56 million, respectively. Therefore, these regions offer a convenient context for exploring the impact of changes in rural family structure on the production decisions of rice farmers. Appendix A, Table A1 presents data on the floating population, sown areas of rice, and output of rice of the sample provinces.

To ensure the randomness and representation of samples, the datasets employed a stratified three-stage sampling method (selecting counties from five provinces; committees or rural villages from counties; and households from committees or rural villages) and probability proportional to the size sampling method. Prior to data collection, enumerators underwent comprehensive training to familiarize themselves with the questionnaire and its objectives. Subsequently, a preliminary study was conducted to assess the enumerators' understanding of the questionnaire and address any ambiguities or concerns. The structured face-to-face questionnaire was then administered to heads of households or their spouses who willingly participated in the study. Our approach prioritized written records to capture detailed information regarding the respondents' rice production operations, household characteristics, and land characteristics over the past year. The project team conducted surveys in 2015, 2017, 2018, and 2019. Since our data did not involve tracking, for study convenience, the four-year data were transformed into pooled cross-section data. To minimize the impact of confounding factors at the year and province levels in the pooled cross-section data, we incorporated year-fixed effects and province-fixed effects through empirical controls. We obtained 1585 valid samples after removing 72 questionnaires from households that did not participate in rice production, households that failed to have any major variables, and households with untruthful data before the empirical analysis.

The dataset was rich and detailed. Firstly, it included comprehensive information about rural families, such as family size, family members' income, age, education, farm experience, migration experience, and remittance details. Secondly, the questionnaire was designed to collect information on each plot of land operated by the household, including farm size, commuting time from home to farmland, the nearest distance from farmland to market, farm inputs (i.e., seeds, fertilizers, pesticides, service, energy, and other inputs), as well as data on rice yield.

### *3.2. Variable Selection*

#### 3.2.1. Dependent Variable: Productivity and Efficiency

(1) Single-factor productivity

Equation (2) was used to determine the single-factor productivity of farmers. In this equation, the value of rice output is referred to as the farm output, while the land, labor, and capital are the farm input factors. Specifically, the sown area of rice production represents the land input factor, the amount of labor time dedicated to rice production represents the labor input factor, and the total cost of farm inputs, such as seeds, fertilizers, pesticides, service, energy, and other inputs used in the rice production process, represents the capital input factor.

(2) TE

In this study, a one-step SFA was used to examine TE. This approach consists of two components: the frontier production model and the technical inefficiency model. The frontier production model includes both output and input variables. As mentioned earlier, the value of rice output is referred to as the farm output, while the land, labor, and capital are the farm input variables. The technical inefficiency model encompasses core independent variables, farmer characteristics, family characteristics, and farm characteristics.

3.2.2. Core Independent Variable: Changes in Rural Family Structure

Referring to Meng et al. (2016) [4], our research had a specific focus on investigating the interdependent relationship between husband and wife within rural families. Our primary objective was to comprehend the changes in family structure that occur when spouses with different immigration statuses are involved. We adopted the definition of "migration" as individuals engaging in off-farm work outside the county for over six months in the current year [4,48]. Our focus was specifically on cross-county migration (moving outside the home county) because within-county migration does not cause as significant changes in family structure since it involves relatively short distances. These migrant workers usually commute daily between their home and their workplace [49], without changing the production and lifestyle of local farmers.

The classification of the changes in family structure presents a significant challenge in this study, as these structures are not necessarily mutually exclusive. For example, some families may experience both couples' joint migration and individual migrations. Moreover, when multiple married couples within the same family exhibit diverse migration patterns, it becomes challenging to pinpoint the specific impact of each structure on farmers' production decisions. To this end, we undertook several initiatives, drawing inspiration from prior research practices [4,50].

First, we assigned a unique number to each family member and established the following classification rules:

(*i*) We determined whether the family exhibited joint migration of couples. If this condition was met, we classified the family structure as "couples' joint migration".

(*ii*) If the family did not fall into category (*i*), we then determined whether it exhibited one spouse's migration. If this was the case, we classified the family structure as "couples' split migration".

(*iii*) If the family did not fit into either category (*i*) or category (*ii*), we further determined whether there was migration involving unmarried sons, daughters, or other family members. If this type of migration existed, classified the family structure as "others' migration".

(*iv*) If the family did not match any of the previously defined categories (i.e., categories (*i*), (*ii*), or (*iii*)), it was classified as NM.

Second, in our empirical analysis, we conducted several robustness tests:

(*i*) We eliminated confounding samples by excluding farmers with multiple extended families, including those with multiple married brothers, to re-estimate the primary outcome.

(*ii*) Building upon step (*i*), we focused solely on stem families and re-estimated the primary outcome. The term "stem family" here refers to a direct family consisting of two or more generations of couples, with each generation limited to one couple at most, and no disconnection in between.

(*iii*) We further explored the long-term effect of changes in family structure by redefining "migrants" as individuals engaged in off-farm work outside the county for a duration of "a minimum of two consecutive years" and "a minimum of three consecutive years", and re-estimated the primary outcome.

These measures were taken to guarantee the clarity and accuracy of our classification and empirical outcomes. We also took into account the choice of regions for migrant workers (i.e., inside and outside the province). Figure 1 displays the various types of changes in family structure and their proportions in the sample. Couples' joint migration, couples' split migration, and others' migration accounted for 21%, 15%, and 22%, respectively. The proportion of couples' joint migration inside the province and couples' joint migration outside the province reached 11.15% and 10%, gradually emerging as the predominant migration pattern in China.

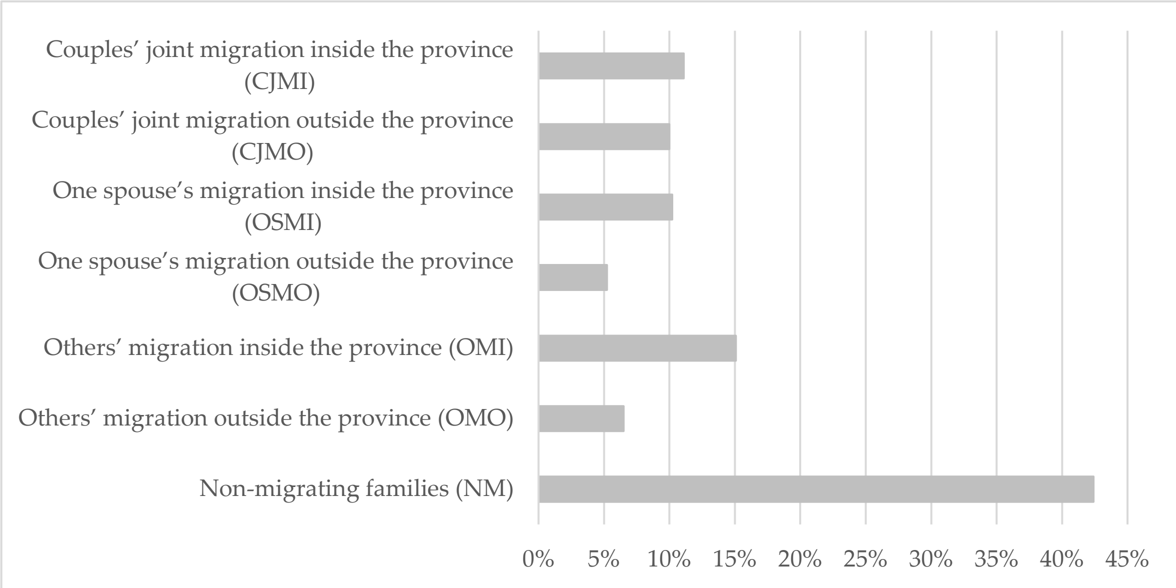


**Figure 1.** Percentage distribution of the structure of families (%). Sources: Authors' calculation based on the survey data.

#### 3.2.3. Control Variables

Following the existing literature [51–53], we controlled for various variables related to farmers, families, and farms. Farmer characteristics included variables such as the number of farm laborers and their age, education, and health status. Family characteristics included variables such as size, male, cadres, off-farm income, and dependency. Acknowledging the influence of the household head on decision-making [19,20], we controlled for the migration status of the household head. Farm characteristics consisted of cultivated area, land fragmentation, commuting time from home to farmland, and the nearest distance from farmland to market. Additionally, province and year dummy variables were also included in the model in order to capture the effects of unobserved economic, social, and other factors.

#### 3.2.4. Descriptive Statistics of Variables

Table 1 presents the definitions and descriptive statistics of the variables covered in this study. In terms of land productivity, rice output value per unit of land is roughly 2456 EUR/ha. For labor productivity, the rice output value per labor day is roughly EUR 29. Regarding capital productivity, the average ratio of the rice output value to the capital of rice inputs is about 2.98. The average TE is calculated to be 0.86, indicating that rice farmers haven not achieved the maximum output using current technology, suggesting partial efficiency dissipation.

## 4. Results

### *4.1. The Impact of Changes in Rural Family Structure on Single-Factor Productivity*

We estimate the impact of changes in rural family structure on land productivity, labor productivity, and capital productivity with Equation (6), as presented in Table 2.

**Table 2.** The impact of changes in rural family structure on single-factor productivity.

| | (1) | (2) | (3) |
|---|---|---|---|
| **Variable Names** | **Land Productivity** | **Labor Productivity** | **Capital Productivity** |
| **Changes in Rural Family Structure (ref. NM)** | | | |
| **Couples' joint migration** | | | |
| CJMI | −132.664 * | 4.767 | 0.631 |
| | (77.537) | (3.903) | (0.617) |
| CJMO | 404.652 *** | 15.701 *** | 0.567 ** |
| | (126.738) | (5.393) | (0.232) |
| **Couples' split migration** | | | |
| OSMI | −71.042 | 7.671 | 0.283 |
| | (71.261) | (5.903) | (0.190) |
| OSMO | 648.880 | 11.230 * | 0.926 *** |
| | (430.795) | (6.085) | (0.343) |
| **Others' migration** | | | |
| TOMI | −66.871 | −2.132 | 2.130 |
| | (102.802) | (6.119) | (1.854) |
| TOMO | 372.284 | 19.761 | 0.661 |
| | (254.513) | (17.497) | (0.420) |
| Control variables | Yes | Yes | Yes |
| Year dummy | Yes | Yes | Yes |
| Province dummy | Yes | Yes | Yes |
| _cons | 1872.846 *** | 4.774 | −1.620 |
| | (437.085) | (18.714) | (4.923) |
| $R^2$ | 0.040 | 0.145 | 0.013 |
| Obs. | | 1585 | |

Note: Standard errors are in parenthesis, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Control variables include Farm laborers, Age, Education, Health, Size, Male, Cadres, Migration of householder, Off-farm income, Dependency, Cultivated area, Fragmentation, Commute, and Distance listed in Table 1.

The results show that the impact of changes in rural family structure on single-factor productivity is heterogeneous. Compared to the reference group (NM), families with couples' joint migration outside the province exhibit significantly higher levels of labor productivity, land productivity, and capital productivity. Specifically, after controlling for province and year dummy variables, we observe that the rice output value per ha is, on average, EUR 405 higher ($p < 0.01$) than that of NM. Moreover, the rice output value per day is EUR 16 higher ($p < 0.01$), and the output–input ratio is 57% higher ($p < 0.05$) than that of NM. Interestingly, for the family with couples' joint migration inside the province, the rice output value per ha is about EUR 133 lower ($p < 0.1$) than that of NM. Additionally, the output–input ratio of the one spouse's migration outside the province is 93% higher than that of NM. Other types of changes in rural family structure, such as one spouse's migration inside the province, others' migration inside the province, and others' migration outside the province, do not exhibit significant differences compared to NM.

The results in Table 2 show that significant outcomes are observed only with certain types of changes in rural family structure. Couples' joint migration seems to be particularly sensitive. Families with couples' joint migration outside the province exhibit comparative advantages with regard to labor, land, and capital productivity, which indicates that the positive effect of income transfers from migrants outweighs the negative lost-labor effect. In contrast, families with couples' joint migration inside the province have lower land productivity, which indicates that the negative lost-labor effect exceeds the positive effect of income transfers from migrants.

### *4.2. TE Estimation with the One-Step SFA*

Single-factor productivity measures the output capacity of a specific factor, while TE offers a comprehensive assessment of farmers' capability to achieve maximum output through existing technologies. Columns (1) and (2) in Table 3 report the results of the one-step SFA's estimated frontier production model and technical inefficiency model, respectively.

**Table 3.** The results of the one-step SFA.

| | **(1)** | | **(2)** |
|---|---|---|---|
| **Variable Names** | **Frontier** | **Variable Names** | **Inefficiency** |
| Lnland | 0.693 *** | **Changes in Rural Family Structure (ref. NM)** | |
| | (0.168) | **Couples' Joint Migration** | |
| Lnlabor | 0.143 * | CJMI | −0.087 |
| | (0.082) | | (0.273) |
| Lncapital | −0.100 | CJMO | −2.764 *** |
| | (0.126) | | (0.565) |
| Lnland × Lnland | −0.031 ** | **Couples' Split Migration** | |
| | (0.015) | OSMI | −0.247 |
| Lnlabor × Lnlabor | 0.002 | | (0.274) |
| | (0.004) | OSMO | −1.015 ** |
| Lncapital × Lncapital | 0.022 ** | | (0.407) |
| | (0.009) | **Others' Migration** | |
| Lnland × Lnlabor | 0.035 *** | TOMI | −0.240 |
| | (0.012) | | (0.242) |
| Lnland × Lncapital | 0.001 | TOMO | −1.398 *** |
| | (0.021) | | (0.474) |
| Lnlabor × Lncapital | −0.021 * | Control variables | Yes |
| | (0.011) | Year dummy | Yes |
| Year dummy | Yes | Province dummy | Yes |
| Province dummy | Yes | _cons | −1.648 * |
| _cons | 7.344 *** | | (0.844) |
| | (0.538) | Obs. | 1585 |
| $\sigma^2$ | 1.378 *** | | |
| | (0.193) | | |
| $\gamma$ | 0.976 *** | | |
| | (0.321) | | |
| TE | 0.861 | | |
| Log likelihood | 89.94 | | |
| Obs. | 1585 | | |

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. According to Equation (4), a negative sign of the coefficient of technical inefficiency indicates that each variable has a positive impact on TE, while a positive sign suggests that each variable has a negative impact on TE. Control variables include Farm laborers, Age, Education, Health, Size, Male, Cadres, Migration of householder, Off-farm income, Dependency, Cultivated area, Fragmentation, Commute, and Distance listed in Table 1.

The results show that the proportion of technical inefficiency terms in the total composite variance (value $\gamma$) is approximately 0.976 and statistically significant at the 1% level. This suggests that the difference between the actual and ideal output is predominantly attributable to technical inefficiency, supporting the suitability of applying the SFA model. The average TE stands at around 0.86, indicating that farmers have not reached maximum efficiency and can still achieve output growth by raising their degree of efficiency.

The frontier function model in Table 3 demonstrates that increasing the marginal inputs of labor and farmland can significantly increase the marginal output of rice. Farmland is still more scarce in rural China than labor, as evidenced by the fact that more farmland inputs can further increase the productivity of the labor input. Farmers have the potential to enhance labor productivity by increasing the input into their farmland. In the production of farms, capital plays an important role. A U-shaped curve represents the relationship between the marginal capital input and the marginal output of rice. Notably, capital significantly weakens the impact of labor on output, exhibiting a substitution effect on labor.

The technical inefficiency model in Table 3 shows that the impact of changes in rural family structure on TE is heterogeneous. Compared to NM, the families with migrants outside the province display a higher capability to achieve technological progress, indicating significant advantages in utilizing frontier agricultural technologies to reach the maximum potential output. However, there is no significant difference in TE between the families with migrants inside the province and NM.

During our survey, we observed that migrants inside the province generally exhibit the phenomenon of "farming in busy season and working in slack season". This behavior is shaped by the convenience of returning to their home region and engaging in seasonal migration between their workplace and their home. In contrast, migrating outside the province involves higher costs [13]. When families face a trade-off between off-farm work and farm production, the opportunity cost of part-time farming rises. Consequently, with the proportion of farm income decreasing, families with migrants inside the province reduce their efforts in farm production and shift their focus towards off-farm work.

### *4.3. Change in the Estimated Sample*

Firstly, Meng et al. (2016) [4] pointed out that when multiple married couples within the same family exhibit diverse migration structures, we are not able to identify which couples are responsible for the impact of the changes in family structure on production decisions. Therefore, we eliminated confounding samples by excluding farmers with multiple extended families, including those with multiple married brothers, to re-estimate the primary outcome. The results in columns (1)–(3) of Table 4 are consistent with those in Table 2, and the results in columns (1) and (3) of Table 5 are consistent with those in Table 3. This suggests that the results remain robust when we exclude the confounded samples.

**Table 4.** The results of robustness tests for single-factor productivity.

| Variable Names | (1) Excluding Samples Containing Multiple Extended Families | (2) | (3) | (4) Migration Persisting for a Minimum of Two Consecutive Years | (5) | (6) |
|---|---|---|---|---|---|---|
| | Land Productivity | Labor Productivity | Capital Productivity | Land Productivity | Labor Productivity | Capital Productivity |
| **Changes in Rural Family Structure (ref. NM)** | | | | | | |
| **Couples' Joint Migration** | | | | | | |
| CJMI | −176.840 * | 4.016 | 0.574 | −140.718 * | 4.594 | 0.647 |
| | (91.310) | (3.797) | (0.848) | (85.394) | (3.695) | (0.649) |
| CJMO | 401.708 *** | 13.884 ** | 0.517 ** | 378.421 *** | 9.592 ** | 0.581 ** |
| | (150.169) | (5.923) | (0.236) | (144.654) | (3.811) | (0.245) |
| **Couples' Split Migration** | | | | | | |
| OSMI | −13.323 | 7.825 | 0.287 | −112.575 | 1.691 | 0.220 |
| | (76.073) | (6.962) | (0.283) | (81.466) | (3.356) | (0.191) |
| OSMO | 786.685 | 11.843 * | 0.965 ** | 632.588 | 9.077 | 0.909 *** |
| | (522.111) | (7.164) | (0.394) | (421.215) | (6.055) | (0.340) |
| **Others' Migration** | | | | | | |
| TOMI | −64.989 | −2.717 | 2.146 | −69.192 | −0.932 | 2.294 |
| | (108.215) | (6.331) | (1.828) | (111.348) | (5.570) | (2.003) |
| TOMO | 392.335 | 19.532 | 0.679 | 379.101 | 2.398 | 0.636 |
| | (254.150) | (17.502) | (0.423) | (288.474) | (8.130) | (0.437) |
| _cons | 2200.451 *** | 20.146 | −0.959 | 135.574 | 2129.826 *** | 36.376 *** |
| | (419.978) | (19.844) | (4.518) | (108.984) | (347.415) | (13.736) |
| $R^2$ | 0.038 | 0.143 | 0.014 | 0.040 | 0.176 | 0.014 |
| Obs. | | 1432 | | | 1535 | |

Note: Standard errors are in parenthesis, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. We have controlled for variables such as Farm laborers, Age, Education, Health, Size, Male, Cadres, Migration of householder, Off-farm income, Dependency, Cultivated area, Fragmentation, Commute, and Distance listed in Table 1, as well as province dummy variables and year dummy variables.

**Table 5.** The results of robustness tests for the one-step SFA.

| | (1) | (2) | | (3) | (4) |
|---|---|---|---|---|---|
| **Variable Names** | **Frontier$_1$** | **Frontier$_2$** | **Variable Names** | **Inefficiency$_1$** | **Inefficiency$_2$** |
| Lnland | 0.638 *** | 0.678 *** | **Changes in Rural Family Structure (ref. NM)** | | |
| | (0.170) | (0.173) | **Couples' Joint Migration** | | |
| Lnlabor | 0.150 * | 0.172 ** | CJMI | −0.075 | −0.137 |
| | (0.087) | (0.086) | | (0.302) | (0.281) |
| Lncapital | −0.055 | −0.112 | CJMO | −2.542 *** | −2.885 *** |
| | (0.124) | (0.129) | | (0.550) | (0.610) |
| Lnland × Lnland | −0.035 ** | −0.032 ** | **Couples' Split Migration** | | |
| | (0.016) | (0.016) | OSMI | −0.524 * | −0.256 |
| Lnlabor × Lnlabor | 0.004 | −0.001 | | (0.312) | (0.276) |
| | (0.004) | (0.004) | OSMO | −1.221 *** | −0.978 ** |
| Lncapital × Lncapital | 0.019 ** | 0.023 *** | | (0.442) | (0.418) |
| | (0.008) | (0.009) | **Others' Migration** | | |
| Lnland × Lnlabor | 0.038 *** | 0.038 *** | TOMI | −0.270 | −0.285 |
| | (0.012) | (0.012) | | (0.246) | (0.251) |
| Lnland × Lncapital | 0.006 | −0.000 | TOMO | −1.414 *** | −1.389 *** |
| | (0.021) | (0.021) | | (0.471) | (0.497) |
| Lnlabor × Lncapital | −0.024 ** | −0.021 * | _cons | −1.306 | −1.873 * |
| | (0.012) | (0.012) | | (1.069) | (1.001) |
| _cons | 7.180 *** | 7.305 *** | Obs. | 1432 | 1535 |
| | (0.540) | (0.556) | | | |
| $\sigma^2$ | 1.857 *** | 2.093 *** | | | |
| | (0.603) | (0.219) | | | |
| $\gamma$ | 0.982 *** | 0.989 *** | | | |
| | (0.352) | (0.158) | | | |
| TE | 0.860 | 0.862 | | | |
| Log likelihood | 73.813 | 85.764 | | | |
| Obs. | 1432 | 1535 | | | |

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. The results labeled as Frontier$_1$ and Inefficiency$_1$ were estimated using the one-step SFA for a sample excluding observations containing multiple extended families. Conversely, the results labeled as Frontier$_2$ and Inefficiency$_2$ were estimated using the one-step SFA for a sample comprising observations where migration persisted for a minimum of two consecutive years. According to Equation (4), a negative sign of the coefficient of technical inefficiency indicates that each variable has a positive impact on TE, while a positive sign suggests that each variable has a negative impact on TE. We have controlled for variables such as Farm laborers, Age, Education, Health, Size, Male, Cadres, Migration of householder, Off-farm income, Dependency, Cultivated area, Fragmentation, Commute, and Distance listed in Table 1, as well as province dummy variables and year dummy variables.

Secondly, if there are substantial variations in the structures of families prior to migration, our estimates may become biased. To address this concern, we performed an additional analysis by only including a sample of stem families and re-estimating the primary outcome. By focusing solely on stem families, our aim is to minimize the impact of the original family form. This ensured that the heterogeneous effects on productivity and efficiency of farmers can be attributed to changes in family structures, making our classification and results more reliable. The results in columns (1)–(3) of Table A2 and columns (1) and (3) of Table A3 are consistent with the previous results, providing further evidence that our results are representative and robust.

### 4.4. Consecutive Years of Migration

Yeboah and Jayne (2018) [54] showed that the effect of migration on production decisions exhibits a time lag, prompting the inquiry of whether the impact of changes in rural family structure on productivity and efficiency of farmers varies over the years. We captured the duration of each family member's migration with the question "If individuals engage in off-farm work for an extended period, how many consecutive years?". To explore the long-term effect, we redefined "migrants" as individuals engaged in off-farm work outside the county for a duration of "a minimum of two consecutive years" and "a minimum of three consecutive years", and re-estimated the primary outcome.

The results in columns (4)–(6) of Table 4 and columns (2) and (4 of Table 5 are consistent with the previous results, affirming the robustness of the results in the sample with a duration of "a minimum of two consecutive years". Additionally, the results in columns (4)–(6) of Table A2 and columns (2) and (4) of Table A3 show that the families with couples' joint migration outside the province and one spouse's migration outside the province, with a duration of "a minimum of three consecutive years", are consistent with the outcomes in Tables 2 and 3. Although the families with couples' joint migration inside the province show a negative effect on land productivity, the result is not statistically significant. One possible explanation for this is that, in the long run, these families tend to adjust land resources through farmland transfer or changes in planting structure, thereby reducing the negative effect of migration on land productivity.

### *4.5. Propensity Score Matching Results*

To address the self-selecting nature of families' migration behavior, we employed the PSM method to conduct additional tests on the results. Non-migrating families were identified as the control group, while changes in family structure were divided into six groups, with each group assigned to the treatment group. The matching covariates included the characteristics of farmers, families, and farms as listed in Table 1. For each pair comparison, we report the average treatment effect for the treated (ATT) on single factor productivity and TE score. The results, as presented in Table 6, exhibit remarkable similarity and are generally consistent with the primary outcome. Consequently, our baseline results remain robust after using the PSM to mitigate selection bias.

**Table 6.** The results of PSM.

| Variable Names | Land Productivity | | Labor Productivity | | Capital Productivity | | TE Score | |
|---|---|---|---|---|---|---|---|---|
| | ATT | t-Value | ATT | t-Value | ATT | t-Value | ATT | t-Value |
| **Changes in Rural Family Structure (ref. NM)** | | | | | | | | |
| **Couples' Joint Migration** | | | | | | | | |
| CJMI | −163.592 * | −1.89 | 5.762 | 1.51 | 0.657 | 1.24 | −0.012 | −0.58 |
| CJMO | 443.241 *** | 3.80 | 19.480 *** | 3.65 | 0.349 ** | 2.20 | 0.075 *** | 4.10 |
| **Couples' Split Migration** | | | | | | | | |
| OSMI | −41.357 | −0.55 | 6.399 | 0.90 | 0.263 | 1.21 | −0.008 | −0.51 |
| OSMO | 638.092 | 1.47 | 10.418 | 1.51 | 0.734 ** | 2.23 | 0.051 *** | 2.65 |
| **Others' Migration** | | | | | | | | |
| TOMI | −12.811 | −0.06 | 5.585 | 0.70 | 2.129 | 1.19 | 0.009 | 0.56 |
| TOMO | 357.534 | 1.39 | 29.842 | 1.52 | 0.165 | 0.55 | 0.080 *** | 4.11 |

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Estimated by nearest neighbor matching, and the matching method successfully satisfied both the balancing hypothesis and the common support assumption. For more detailed results, please consult the primary author.

## 5. Discussion

Based on a survey of rice farmers in five provinces of China, this study explores the impact of changes in rural family structure on agricultural productivity and efficiency. We first investigate the heterogeneous effects of changes in rural family structure on single-factor productivity, including land, labor, and capital productivity. Then, a one-step SFA is employed to assess the production frontier and estimate inefficiency. Finally, we use multiple approaches to examine the results and come to similar conclusions. Our research has a specific focus on investigating the interdependent relationship between spouses within farm couples, particularly when both partners are involved in off-farm employment.

Since less attention has been paid to the effects of changes in family structure on the production decisions of rural families, the purpose of this study is to enrich the existing literature by expanding the perspective to a deeper frame of reference. Our empirical results suggest that the structural–spatial relationship of any migration that takes place cannot be ignored. This is consistent with Meng et al. (2016) [5], Zhou et al. (2020) [22], and Kocatepe et al. (2023) [55]. Our findings also emphasize the importance of considering regional differences in migration, which supports to some extent the views regarding migration region heterogeneity and distance heterogeneity mentioned in the studies of Lim (2019) [26], Xu and Li (2023) [56], and Piyapromdee (2021) [57].

Research on the relationship between rural–urban migration and agricultural performance presents mixed and inconclusive outcomes. Previous studies have noted that rural families experiencing migration will balance both the negative effects of labor loss and the positive effects of remittances when making production strategy decisions [57]. This study provides evidence of the heterogeneous effects of changes in rural family structure on agricultural productivity and efficiency. On the one hand, compared to non-migrating families, we observe that families with couples' joint migration outside the province display higher single-factor productivity and technical efficiency. This supports the idea that the positive effects of remittances outweigh the negative effects of labor loss, which aligns with the findings of Chiodi et al. (2012) [11] and Amare and Shiferaw (2017) [58]. On the other hand, we are cautious in concluding that land productivity is lower for families with couples' joint migration inside the province. This suggests that the negative effects of labor loss outweigh the positive effects of remittances in this case, consistent with the work of Holden et al. (2004) [7] and Shi et al. (2011) [59]. In addition, there is no significant effect on the single-factor productivity for the families with one spouse's migration inside the province and others' migration beyond spouses. Similarly, there is no significant effect on the technical efficiency of families with migration inside the province. These findings are consistent with McCarthy et al. (2009) [13] and Feng et al. (2010) [5]. A possible explanation for this is that these families may compensate for the loss of household labor by reducing the leisure time or other low-return activities of surplus farm labor, as suggested by Wang et al. (2014) [60].

## 6. Conclusions and Suggestions

Our study is essential for understanding the relationship between migration and sustainable rural and urban development. Over the past three decades, China has experienced significant transformations in its societal structure, driven by industrialization, urbanization, and the migration of young people to engage in off-farm work in urban areas. By examining how changes in rural family structure affect agricultural productivity and efficiency, our study not only contributes to achieving more balanced and sustainable development across regions, but also plays a critical role in ensuring food security in China.

Over the years, migration research has primarily focused on individuals' movement to and settlement processes in urban areas. In this study, our attention turns to the individual differences and the division of the labor force within families. Our findings indicate that families experiencing diverse structural changes might choose distinct production strategies. Our key findings are summarized as follows: (1) Only certain types of changes in the rural family structure exert a significant impact on agricultural productivity and efficiency. (2) Rural families experiencing migration in different regions often adopt distinct production strategies. (3) Couples' joint migration seems to be particularly important in agricultural productivity and efficiency. Compared to non-migrating families, families with couples' joint migration outside the province exhibit higher single-factor productivity and technical efficiency, while families with couples' joint migration inside the province show lower land productivity.

The findings in this study have several important policy implications for sustainable rural and urban development. First, the significant migration of young rural labor to cities further aggravates the aging of the agricultural labor force in rural areas [23–25]. This demographic shift presents challenges to agricultural productivity and sustainability, necessitating targeted policies to support the remaining labor force. We recommend that the government allocate resources towards the improvement and development of the rural infrastructure, with a particular emphasis on agricultural irrigation facilities and the availability of advanced agricultural machinery services. In the long run, these investments will not only promote food security by supporting sustained agricultural output, but also enhance the well-being of the remaining agricultural labor force. Second, while extended migration distances may lead to higher income for migrant workers, they also come with increased costs related to time, transportation, and information [26]. We suggest that the government take measures to facilitate convenient transportation for migrant workers commuting between their hometowns and their off-farm work locations, particularly for those migrating to outside the province. Moreover, implementing different levels of transport subsidies or transitional living subsidies for migrant workers who migrate across regions and provinces is a valuable consideration [56].

Although this study focuses specifically on the case of China, its conclusions and recommendations are applicable to other developing countries that are experiencing rapid urbanization or large rural–urban migration. Migrant workers play a vital role in the process of urbanization and in achieving balanced and sustainable development between regions. On the one hand, rural–urban migration provides cities with a large supply of affordable labor, which supports urban economic growth and development. On the other hand, the income and remittances of migrant workers are effective ways for many rural families to escape poverty [61]. Understanding the impact of rural couples leaving their hometown simultaneously or migrating alone is crucial for formulating and evaluating specific policies. For central government, we recommend strengthening social security measures and creating employment opportunities for migrant workers, with specific attention to supporting migrant couples. Local governments should implement measures to enhance the welfare and well-being of those left behind. Since those remaining in rural areas may face increased agricultural production burdens, establishing a socialized service system for public welfare and providing agricultural subsidies are crucial. Additionally, local governments should devise new development strategies to adapt to changes in rural demographics resulting from family migration. As family members migrate to urban areas, issues such as economic opportunities for spouses left behind (most likely the wife), as well as the health and education of the elderly and children, warrant attention not only by scholars but also by policy-makers.

This study still has several deficiencies. First, due to limited data availability and resource allocation, pooled cross-sectional data are used instead of panel data. While multiple approaches were employed to examine the results and come to similar conclusions, there were remaining endogeneity issues that need be addressed in future research. Panel data and various measurement methods can be used to test the findings of this study. Second, the research area was primarily the middle and lower reaches of the Yangtze River, where the local off-farm work market is relatively well-established. However, it is important to note that most rural areas in China lack sufficient off-farm work opportunities. Therefore, future research should concentrate on impoverished and remote regions for a comprehensive understanding of the subject matter.

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## Appendix A

**Table A1.** The floating population, sown areas of rice, and output of rice of sample provinces.

| Province | Floating Population (Million) | Sown Areas of Rice (Million ha) | Output of Rice (Million Ton) |
|---|---|---|---|
| Guangdong | 52.06 | 1.79 | 10.75 |
| Jiangxi | 13.52 | 3.35 | 20.48 |
| Anhui | 13.87 | 2.51 | 16.30 |
| Hubei | 12.76 | 2.29 | 18.77 |
| Hunan | 17.57 | 3.86 | 26.12 |
| Total in China | 375.82 | 29.69 | 209.61 |

Note: Floating population refers to individuals who have left their registered hometowns to reside elsewhere outside their city or district of origin for a period typically exceeding six months. Sources: The data regarding the floating population are from the China Population Census Yearbook 2020. The data for the sown areas of rice and output of rice are from the China Statistical Yearbook 2020.

**Table A2.** The results of robustness tests for single-factor productivity.

| Variable Names | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | A Sample of Stem Families | | | Migration Persisting for a Minimum of Three Consecutive Years | | |
| | Land Productivity | Labor Productivity | Capital Productivity | Land Productivity | Labor Productivity | Capital Productivity |
| **Changes in Rural Family Structure (ref. NM)** | | | | | | |
| **Couples' Joint Migration** | | | | | | |
| CJMI | −168.558 * | 4.206 | 0.604 | −122.212 | 3.417 | 0.709 |
| | (92.756) | (3.948) | (0.846) | (78.664) | (3.712) | (0.666) |
| CJMO | 398.232 *** | 12.529 * | 0.574 ** | 323.487 *** | 8.083 ** | 0.548 ** |
| | (152.365) | (6.402) | (0.254) | (83.515) | (3.701) | (0.262) |
| **Couples' Split Migration** | | | | | | |
| OSMI | −16.988 | 6.973 | 0.331 | −95.335 | 1.378 | 0.245 |
| | (77.693) | (7.226) | (0.295) | (71.154) | (3.298) | (0.196) |
| OSMO | 804.698 | 11.499 | 1.065 ** | 781.085 * | 10.120 | 1.068 *** |
| | (542.364) | (7.566) | (0.417) | (442.048) | (6.274) | (0.372) |
| **Others' Migration** | | | | | | |
| TOMI | −75.544 | −5.522 | 2.299 | −52.606 | −2.594 | 2.518 |
| | (120.858) | (7.273) | (1.924) | (99.999) | (5.349) | (2.196) |
| TOMO | 378.622 | 15.050 | 0.870* | 442.465 | −1.545 | 0.719 |
| | (259.079) | (18.244) | (0.504) | (317.209) | (7.658) | (0.469) |
| _cons | 2320.228 *** | 32.390 | −0.871 | 2382.939 *** | 36.131 *** | −0.330 |
| | (457.401) | (21.383) | (4.806) | (420.485) | (13.930) | (4.227) |
| $R^2$ | 0.041 | 0.150 | 0.016 | 0.041 | 0.187 | 0.014 |
| Obs. | | 1264 | | | 1490 | |

Note: Standard errors are in parenthesis, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. We have controlled for variables such as Farm laborers, Age, Education, Health, Size, Male, Cadres, Migration of householder, Off-farm income, Dependency, Cultivated area, Fragmentation, Commute, and Distance listed in Table 1, as well as province dummy variables and year dummy variables.

**Table A3.** The results of robustness tests for the one-step SFA.

| | (1) | (2) | | (3) | (4) |
|---|---|---|---|---|---|
| **Variable Names** | **Frontier$_1$** | **Frontier$_2$** | **Variable Names** | **Inefficiency$_1$** | **Inefficiency$_2$** |
| Lnland | 0.616 *** | 0.668 *** | **Changes in Rural Family Structure (ref. NM)** | | |
| | (0.174) | (0.174) | **Couples' Joint Migration** | | |
| Lnlabor | 0.144 | 0.174 ** | CJMI | −0.077 | −0.132 |
| | (0.090) | (0.087) | | (0.301) | (0.285) |
| Lncapital | −0.021 | −0.104 | CJMO | −2.580 *** | −2.810 *** |
| | (0.124) | (0.130) | | (0.555) | (0.618) |

**Table A3.** *Cont.*

| | (1) | (2) | | (3) | (4) |
|---|---|---|---|---|---|
| **Variable Names** | **Frontier$_1$** | **Frontier$_2$** | **Variable Names** | **Inefficiency$_1$** | **Inefficiency$_2$** |
| Lnland × Lnland | −0.037 ** | −0.033 ** | **Couples' Split Migration** | | |
| | (0.016) | (0.016) | OSMI | −0.517 * | −0.233 |
| Lnlabor × Lnlabor | 0.005 | −0.001 | | (0.311) | (0.278) |
| | (0.004) | (0.004) | OSMO | −1.236 *** | −0.947 ** |
| Lncapital × Lncapital | 0.016 * | 0.022 ** | | (0.446) | (0.417) |
| | (0.008) | (0.009) | **Others' Migration** | | |
| Lnland × Lnlabor | 0.036 *** | 0.038 *** | TOMI | −0.328 | −0.281 |
| | (0.013) | (0.013) | | (0.248) | (0.261) |
| Lnland × Lncapital | 0.013 | 0.001 | TOMO | −1.491 *** | −1.259 ** |
| | (0.021) | (0.021) | | (0.466) | (0.502) |
| Lnlabor × Lncapital | −0.024 ** | −0.021 * | _cons | −1.252 | −2.244 ** |
| | (0.012) | (0.012) | | (1.111) | (1.027) |
| _cons | 7.135 *** | 7.275 *** | Obs. | 1264 | 1490 |
| | (0.547) | (0.560) | | | |
| $\sigma^2$ | 2.805 *** | 0.886 *** | | | |
| | (0.737) | (0.191) | | | |
| $\gamma$ | 0.981 *** | 0.959 *** | | | |
| | (0.485) | (0.186) | | | |
| TE | 0.856 | 0.862 | | | |
| Log likelihood | 61.422 | 78.565 | | | |
| Obs. | 1264 | 1490 | | | |

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. The results labeled as Frontier$_1$ and Inefficiency$_1$ were estimated using the one-step SFA for a sample of stem families. Conversely, the results labeled as Frontier$_2$ and Inefficiency$_2$ were estimated using the one-step SFA for a sample comprising observations where migration persisted for a minimum of three consecutive years. According to Equation (4), a negative sign of the coefficient of technical inefficiency indicates that each variable has a positive impact on TE, while a positive sign suggests that each variable has a negative impact on TE. We have controlled for variables such as Farm laborers, Age, Education, Health, Size, Male, Cadres, Migration of householder, Off-farm income, Dependency, Cultivated area, Fragmentation, Commute, and Distance listed in Table 1, as well as province dummy variables and year dummy variables.

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