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Analyzing Factors That Affect Rice Production Efficiency and Organic Fertilizer Choices in Vietnam

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Abstract: Rice farmers in Vietnam face many difficulties achieving technical efficiency (TE), which can be measured by the distance to the production frontier, in rice production due to non-optimal combinations of inputs and the influence of household socioeconomic characteristics. This study investigates the TE of rice production by applying stochastic frontier analysis to raw data obtained from the Vietnamese Households Living Standards Survey 2016 (VHLSS 2016) database. In addition, organic fertilizers now demand much attention worldwide because of their environmentally friendly characteristics. Therefore, this study identifies the effects of organic fertilizer choices on the TE of rice production. The results show that farmers in Vietnam achieved 87.6 percent TE and that most factors tested had significant effects on rice production. Instead of rice monoculture, the four main factors with strong and positive effects on TE levels were intensive labor, irrigation, mixing crops instead of rice monoculture, and education. Moreover, this study also revealed that organic fertilizer plays a vital role in growing rice by applying propensity score matching (PSM) between farmers who use or do not use irrigation facilities in rice production. While in the process of building a system, the government should focus on rice producers to strive for maximum efficiency with regard to labor productivity and mixed-crop farming, and to take proper measures to improve rice productivity and quality through the use of organic fertilizers. As a result, this study revealed that the use of organic fertilizers for rice production in Vietnam does not always benefit households' TE.

Keywords: rice production efficiency; stochastic frontier; propensity score matching; organic fertilizer use; irrigation facility; Vietnamese Households Living Standards Survey; selection bias; the average treatment on the treated; nearest neighbor matching; Inverse Probability Weighed Regression; Vietnam

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1. Introduction

Agriculture is an exceedingly important contributor to the Vietnamese economy, accounting for 24% of GDP and generating 20% of export revenues. Over 70% of the national labor force is employed in the agriculture sector, and an additional 6% is employed in the agricultural postproduction sector [1]. Rice is the main crop in the farm household agricultural sector in Vietnam, with 9.3 million hectares (ha) of agricultural land that is primarily used for rice cultivation. The agricultural and rural development sector continue to set a target for rice production of 7.2 to 7.3 million hectares as the cultivated area in 2022. This will be achieved by intensive farming with increased productivity to reach production levels of 43 to 43.9 million tons. Rice production is also a vitally important component of food security in Vietnam as the first criterion the millennium development goals. In addition, the Nationally Determined Contribution (NDC), which is making institutional support for agricultural and all related sectors in Vietnam, was discussed by Nguyen Duc Trung [2]. On the other hand, organic agriculture has been focused upon as one of the sustainable agricultural production systems with low environmental impact and potential contribution to global food supply, while detrimental environmental impacts of conventional agriculture have been critically discussed. For example, Badgley, C. et al. [3] insisted that an organic agricultural production system has the potential to contribute quite substantially to the global food supply. There are many organic-based fertilizer industries active in the area of developed economies (http://www.ecofi.info/ accessed on 10 May 2022), but not active in agricultural production in developing countries.

However, as in many economically developing countries, Vietnamese rice farmers are regarded as inefficient rice producers because of non-optimized input combinations and the influence of rice farm household characteristics. In other words, the technical efficiency (TE) of rice production is closely related to sustainable rice farming practices because they share the same basic elements, such as the use of labor, seed, fertilizers, and pesticides. Rice farmers with high TE might achieve more sustainable production with enough reasonable inputs. Consequently, farmers can expect to expand the global market share for Vietnamese rice with higher quality produce and larger quantities, and can improve farmers' livelihoods.

Several studies have emphasized economic efficiency in agricultural production, especially presenting analyses of TE in the agriculture sectors of economically developing countries. For instance, Watkins et al. [4] use a data envelopment analysis (DEA) approach and report the TE of rice production in Arkansas, the top rice-producing state in the United States, as 0.803, with constant returns to scale (CRTS) as 0.875 and a scale efficiency of 0.92, implying that rice production in Arkansas is remarkably efficient in its use of inputs. Furthermore, the authors estimate allocative efficiency and economic efficiency as 0.711 and 0.622, respectively [4]. Boubacar et al. [5] also use a DEA approach and report the TE of rice-producing farmers in southwestern Niger as 52%. The results show that farm size, experience in rice farming, membership in a cooperative, main occupation, and land ownership directly affect TE [5]. By applying stochastic frontier analysis (SFA), a kind of production function form, Chandio et al. [6] examine the effects of agricultural credits and farm size on the TE of rice productivity in Sindh, Pakistan. The results show that these factors, which include credit, farm size, fertilizer, and labor, significantly influenced rice productivity in the area. The average TE was 0.97, which implies that about half of the rice farmers are as technically efficient (within 3%) as the most efficient farmers. Meanwhile, according to Kompas, the TE of rice production in Vietnam was 0.65 nationwide and 0.78 for the Red River and Mekong River Deltas [7].

This study uses the stochastic production frontier and regional cross-sectional data in order to explain productivity differences among firms by estimating the TE of rice production in Vietnam. Giang [8] reveals that the estimated mean TE of rice production in Vietnam was 83%, and the technical scores of farmers who cultivate market-oriented products such as industrial crops have greater TE than those growing rice and maize. However, the author does not discuss the determinants that affect the TE of rice production itself but discusses the importance of crop diversification, emphasizing that the combination of rice and cash crops in a market-oriented context can contribute to implementing policies for agriculture production in Vietnam. Khai and Yabe [9] estimate the TE of Vietnamese rice farming using SFA and investigate its constituents. The empirical results indicate that rice-farming households in Vietnam obtain an average TE of 81.6%. Khai and Yabe [9] find that the level of TE is strongly influenced by inherent factors, including labor, investment in rice land, irrigation systems, ethnicity, and education. However, their study uses national data from the Vietnam Household Standard Survey 2005–2006 (VHLSS 2006) to investigate the factors that affect rice output from the efficient use of the inputs to rice production. Rice production in Vietnam has since improved and a newer version of the VHLSS is available. Therefore, following Khai and Yabe [9], we employ the 2016 version of the VHLSS and use SFA to estimate the TE of Vietnamese rice farming. The results are expected to reveal the most crucially important element inputs for these farmers. We also discuss the differences between farmers in rice production efficiencies from the viewpoints of irrigation use and organic fertilizer choice by adapting the propensity score matching (PSM) method to the control for self-selection bias.

2. Materials and Methods

2.1. Stochastic Frontier Framework

The stochastic frontier production function, which was proposed independently by both Aigner et al. [10] and Meeusen and van den Broeck [11], has been an important contribution to the econometric modeling of farm production and TE estimation. The stochastic frontier involves the following two random components: one associated with the presence of technical inefficiency and the other a traditional random error. Before the introduction of this model, Aigner and Chu [12], Timmer [13], Afriat [14], Richmond [15], and Schmidt [16] considered estimating deterministic frontier models with values defined as greater than or equal to the observed values of production for different levels of inputs to the production process [17].

Presuming that a farm has a production function $f(X_i,\ \beta)$, then the ith farm would produce $Y_i = f(X,\ \beta)$ if there were no errors or inefficiency. The stochastic production frontier model includes the assumption that each farm potentially produces less than it might because of a level of inefficiency. Specifically,

$$Y_i = f(X_i,\ \beta)\varepsilon_i \tag{1}$$

where Y_i represents output and X_i stands for the input vector of the ith farm. β is the vector of parameter estimates, and ε_i represents the efficiency of the ith farm. Output is also assumed to be subject to random error v_i, suggesting that

$$Y_i = f(X_i,\ \beta)\varepsilon_i \exp(v_i) \tag{2}$$

where v_i is assumed to be independent and identical to $N\left(0,\ \delta_v^2\right)$.

$Y_i = f(X_i,\ \beta)$ is assumed in many forms of production functions, for example, the Cobb–Douglass production function, translog function, and others. Following Khai and Yabe [8], we employ a Cobb–Douglass production function because using the same function and data from the same survey can help identify differences in the TE of rice production in Vietnam between 2006 and 2016.

The natural logarithm of the production function is expressed as:

$$lnY_i = ln[f(X_i,\ \beta)] + ln\varepsilon_i + v_i \tag{3}$$

Assuming that there are k inputs and the production function is log linear, we define the technical inefficiency effect $u_i = ln\varepsilon_i$, which is assumed to be independently exponentially distributed with δ_u^2. Therefore, the production frontier function in Equation (3) becomes

$$lnY_i = \beta_0 + \sum_{k=1}^{k} \beta_{ik} lnX_{ik} + v_i - u_i \tag{4}$$

The technical inefficiency effect can be determined as

$$u_i = \alpha_0 + \sum_{j=1}^{j} \alpha_j Z_{ik} + w_{ij} \tag{5}$$

In this equation, w_{ij} signifies stochastic noise and Z_{ik} stands for exogenous factors that affect rice production. Both α_0 and α_j are parameter estimates such that negative α_j indicates a positive relationship between exogenous factors and the TE of rice production and vice versa. Technical efficiency (TE_i) under the output-oriented ith farm is measured as $TE_i = exp(-u_i)$ and is defined as the ratio of the observed output and frontier output. TE_i must be in the interval (0,1). If TE_i equals 1, then the farm is regarded as operating at the optimal output with technology embodied in the production frontier.

2.2. Data Collection

This study was conducted to examine national data from Vietnam obtained from the VHLSS 2016. The VHLSS has been conducted every two years since 1993 to assess the living conditions in Vietnam. The survey is administered nationwide through face-to-face interviews by the General Statistic Office of Vietnam using household questionnaires, with consultation from the ministries and technical advice from the World Bank.

This study uses rice production data from the VHLSS 2016, which includes data from 9399 rural and urban households. Approximately 3695 household rice farmers were interviewed. After discarding household data where information was missing or unreasonable, the data from a total of 3444 were used for the study.

2.3. Data Description

This study applies a Cobb–Douglas production function with a single output (summary rice quantity harvested in a year) and the following nine input factors: seed expenditures, pesticide expenditures, fertilizer expenditures (comprising chemical fertilizer and organic positive values (self-supplied organic fertilizer or bought)), machinery service expenditures (comprising rental cattle and rental equipment cost with only positive values in total), hired labor for rice production expenditures (individual persons employed by a household to perform rice cultivating tasks), small tools and energy expenditures, and other rice expenditures. Family labor for rice (labor devoted solely to rice farming) was calculated by multiplying the total family labor by the share of rice value in its farm's total revenue, and the rice land area (total land size in rice farming recorded in square meters), with the rice land area measured in hectares, as shown in Table 1. All inputs were calculated from expenditures in Vietnamese currency (thousand VND: the national currency for Vietnam), except for the total farming labor (h), family labor for rice (h) and rice land area (ha). This is because we cannot appreciate the information about both wage rate and land rent for self-supply. Regarding the fertilizer input variables, this study uses fertilizer costs to compare with the fertilizer quantities in an earlier study because both studies calculate variables by the sum of cropping patterns in a year.

Table 1. Statistics of quantitative variables in the TE model.

Variables	**Mean**	**Std. Dev.**	**Coeff. Var.**	**Min**	**Max**
Output					
Rice quantity (kg/year)	4906.2	11,973.1	2.4404	110.0	217,220.0
Inputs					
Seed expenditures (1000VND/year)	1385.3	3545.7	2.5595	18.0	76,049.0
Pesticide costs (1000VND/year)	2343.0	8176.2	3.4897	9.0	113,730.0
Fertilizer expenditures (1000VND/year)	4562.6	10,753.9	2.3570	47.0	181,428.0
Hired labor (1000VND/year)	1007.0	4020.0	3.9920	1.0	101,677.0
Machinery service (1000VND/year)	3176.0	5921.2	1.8644	49.0	67,674.0
Small tools and energy (1000VND/year)	404.1	1167.1	2.8881	1.0	31,024.0
Other rice expenditures (1000VND/year)	231.5	792.5	3.4235	11.0	20,680.0
Total farming labor (h)	2252.8	1747.7	0.7758	20.0	13,096.0
Family labor for rice (h)	1288.6	1260.8	0.9784	0.4	9909.6
Rice land area (ha)	0.9	1.8	2.1059	0.0	31.9
Farm-specific variables					
Percent of rice (%)	0.6	0.3	0.5763	0.0	1.0
Age of household (yrs)	51.0	12.5	0.2446	22.0	104.0
Education of farmers (yrs)	7.3	3.3	0.4467	0.0	12.0
Total farming income (1000VND/year)	78,022.9	167,256.6	2.1437	971.0	4,053,214.0
Non-agricultural income (1000VND/year)	37,734.4	151,526.2	4.0156	0.0	4,031,316.0

Source: Vietnamese Households Living Standards Survey 2016 (VHLSS 2016), n = 3444.

A Cobb–Douglas production function with nine input independent variables was used for this study. The Cobb–Douglas stochastic frontier model is written as follows:

$$lnY_i = \beta_0 + \sum_{k=1}^{9} \beta_{ik} lnX_{ik} + v_i - u_i \quad (6)$$

$$TE_i = \alpha_0 + \sum_{j=1}^{14} \alpha_j Z_{ik} + w_{ij} \quad (7)$$

Subsequently, the Tobit function is applied with TE as the dependent variable to ascertain those factors that affect the TE of households, as shown in Table 2.

Table 2. Definitions of qualitative variables affecting the TE model.

Variables	Definition
Ethnicity	1 = Kinh, 0 = other ethnicity
Members per household	total number
Gender	1 = male, 0 = female
Education level of HH head	0 = no certificate, 1 = elementary school certificate, 2 = others
Age of HH head	0 = younger than 30, 1 = 31–40, 2 = 41–50, 3 = 51–60, 4 = 61–71, 5 = over 71
Marital status	1 = married, 0 = others
Using internet	1 = yes, 0 = no
Non-agricultural income	0 = 0, 1 = positive
Total agricultural income	0 = less than (mean—standard deviation), 1 = between (mean—standard deviation) and mean, 2 = between mean and (mean + standard deviation), 3 = greater than (mean + standard deviation)
Irrigation system	0 = did not employ, 1 = employed
Organic fertilizer use	0 = did not use, 1 = used
Borrowing funds for rice production	0 = did not borrow, 1 = borrowed
Income source	0 = income from other crops was positive, 1 = only rice
Labor–land ratio	Ratio of rice labor to land

Source: Vietnamese Households Living Standards Survey 2016 (VHLSS 2016), n = 3444.

The average land area used for rice production in Vietnam is quite small at around 0.85 ha, with a range of 0.034–31.88 ha. The average age of household heads is 51, with a range of 22–104 years old; their average year of education is only around 7 years, ranging from 0–12 years, which suggests that Vietnamese rice farmers have relied more heavily on experience than education. Among the rice production inputs, fertilizer expenditure plays the most important role of all expenses, with an average value of around 4.5 million VND, accounting for 30% of all expenses. The total value of farming activities is about 78 million VND, a considerable increase from 2006, when the value was only 13.5 million VND. It is noteworthy that farmers are not only growing rice but also participate in growing other crops.

3. Results and Discussion

3.1. Technical Efficiency

The results presented in Table 3 show the OLS model estimates and the stochastic frontier function model for estimating TE. The coefficient of determination (R^2) is equal to 0.96, indicating that around 96% of the dependent variable is explained by the independent variables included in the OLS model. All parameter estimates in both models are significant with the exception of the family labor for rice variable, which is not significant in the maximum likelihood estimation model.

Table 3. Estimated results of the stochastic frontier production function.

Variables	OLS			Stochastic Frontier		
	Coefficient	**Std. Err.**	**P > |t|**	**Coefficient**	**Std. Err.**	**P > |z|**
Seed expenditures	0.0159	0.0069	0.020	0.0146	0.0059	0.014
Pesticide costs	0.0474	0.0046	0.000	0.0473	0.0040	0.000
Fertilizer costs	0.1763	0.0073	0.000	0.1141	0.0073	0.000
Hired labor	0.0028	0.0011	0.010	0.0029	0.0010	0.002
Small tools and energy	0.0068	0.0026	0.009	0.0056	0.0023	0.012
Machinery services	0.0138	0.0014	0.000	0.0101	0.0012	0.000
Other rice expenditures	0.0073	0.0014	0.000	0.0030	0.0012	0.012
Family labor for rice	0.0057	0.0027	0.036	0.0022	0.0024	0.355
Rice land area	0.7503	0.0092	0.000	0.8257	0.0088	0.000
Constant	−0.5178	0.0358	0.000	−0.4593	0.0310	0.000
Adj R-squared	0.9608					
F-statistic model	9369.49					
F-statistic CRTS	42.15					
sigma_v				0.1397		
sigma_u				0.1428		
Lambda				1.022	0.006	
Log Likelihood				749.06		

Note: LR test of sigma_u = 0: chibar2 = 4.2×10^2; Prob > = chibar2 = 0.000.

Land area is the most important factor affecting rice production. Expanding the land area by 1% would increase output by 0.83%. Other factors, such as fertilizer, machinery, and pesticides, also have significant effects on rice farming. Increasing fertilizer, pesticide, and machinery costs by 1% can be expected to increase rice yields by 0.11%, 0.05%, and 0.01%, respectively. Additionally, the results obtained by H. Le Ngoc [18] indicate that the expenditures on seed, land, and fertilizer are the primary determinants of the TE of rice production. By contrast, hired labor and other costs (postage, advertising, marketing, production insurance, plant protection fees, field improvement fees, extension fees, administrative management fees, and feed for working cattle) have the lowest effect on TE, with coefficient values equivalent to 0.003. The results of this study demonstrate that rice land area and fertilizer have the same values as those obtained by Khai and Yabe [9]. However, the family labor for rice and hired labor variables in the two studies have significantly different values. As might be readily apparent, the respective coefficients of family labor costs and hired labor for rice in 2016 (0.0022 and 0.0029, respectively) were much smaller than those in 2006 (0.0229 and 0.0053, respectively). Furthermore, we found the same result as Hoa-Thi-Minh Nguyen et.al. [19] in that the strong economic growth and rapid expansion of non-agricultural sectors have moved a substantial amount of rural labor out of agriculture. Perhaps Vietnamese rice farmers have replaced human physical labor in agricultural production with machine power. Moreover, a great transformation might have occurred over 10 years (2006–2016) as machinery services were steadily replaced by newer technologies. Although the coefficient of human labor use was smaller in 2016 than in 2006, the coefficient of machinery services in 2016 was also slightly smaller than that in 2006.

The results of the likelihood ratio test for the exponential model (chibar2(01)) = 4.2×10^2, which is different from zero and significant at the 1% level. This result confirms that the null hypothesis of no technical inefficiency in the model can be rejected at the 1% significance level, which means that rice farm households have organized their rice production with a certain level of inefficiency. The restricted residual sum of squares was also estimated. The computed F statistic of 42.15 was larger than the critical F value at the 1% significance level. Consequently, the null hypothesis of constant returns to scale is rejected, suggesting that technology does not display constant returns to scale.

3.2. Factors Affecting TE

A Tobit model is applied to estimate TE using the crucially important socioeconomic independent variables presented in Table 4. The aim was to elucidate the factors that affect rice production technical inefficiency in Vietnam.

Table 4. Technical efficiency: a comparison between models with/without irrigation.

Variables	All Samples (3444)	With Irrigation (1260)	Without Irrigation (2184)
Organic fertilizer use	−0.0055 **	−0.0082 **	−0.0054
Irrigation use	0.0178 ***		
Loan	0.0143	0.0300 **	0.0110
Ethnicity	0.0159 ***	0.0034	0.0133 ***
Education	0.0020 ***	0.0005	0.0124 ***
Gender	0.0035	0.0080	0.0017
Age of household head	0.0009	−0.0024	0.0024
Member	−0.0031 ***	−0.0003	−0.0045 ***
Marriage status	0.0034	−0.0030	0.0065
Using internet	0.0014	−0.0092 **	0.0080
Non-agriculture income	0.0098 **	−0.0033	0.0174 ***
Total agriculture income	0.0093 ***	0.0047	0.0123 ***
Rate income from rice	0.0108 **	0.0047	0.0129
Labor–land ratio	0.0197 ***	0.0108 ***	0.0227 ***
Constant	0.8289 ***	0.8879 ***	0.8200 ***
Sigma	0.0871	0.5549	0.0555

Note: ** significant at 5%; *** significant at 1%.

The estimation results for all farmers indicate all variables in the model are significant except loan, gender, age, marriage status, and internet use. The most important factor affecting farmers' incomes is the labor–land ratio, which has the highest positive coefficient value of 0.0197. The results suggest that the labor–land ratio factor plays an important role in the TE of households, as follows: the more intensively labor input can be applied to rice land, the higher the TE of households. Irrigation has a positive coefficient of 0.0178 in this model, with significance at the 1% level. The results also suggest that irrigation is the second most important factor that affects rice production TE. In this study, farmers who participated in an irrigation system achieved markedly higher rice productivity.

3.3. Impact of Irrigation Facility Evaluation

Based on the discussion of rice production efficiencies for all samples, the estimated production efficiencies among farmers who use irrigation and those who do not are also shown in Table 4. These results suggest that the factors that affect TE are approximately the same for the groups "All sample (3444)" and "Without irrigation (2184)". The size of the coefficients was also approximately equal in both groups. On the other hand, organic fertilizer use negatively affects both the "All sample (3444)" and "With irrigation (1260)" groups.

However, the rates of farmers who used organic fertilizer in the groups "With irrigation (1260)" and "Without irrigation (2184)" can be found in Table 5. They were, respectively, about 25.8% (325/1260) and 42.9% (938/2184). This result indicated that farmers who use organic fertilizer in the group "With irrigation (1260)" might strongly influence the evaluation of TE related to the irrigation facility.

Table 5. Impact of using an irrigation facility and organic fertilizer: PSM model.

		Using Organic Fertilizer	
		◯ Yes	× No
Using irrigation facility	◯ Yes	Farmers A: 325	Farmers C: 935
	× No	Farmers B: 938	Farmers D: 1246

Source: Vietnamese Households Living Standards Survey 2016 (VHLSS 2016), n = 3444.

3.4. Propensity Score Matching among Farmers without Organic Fertilizer Use

In the next step, we apply propensity score matching (PSM) to quantify the impact of an irrigation system on rice production by matching individual farmers who were or were not using the irrigation system. This applied only to farmers who did not use organic fertilizer, between farmers C and farmers D in Table 5, in order to evaluate the impact of using an irrigation system properly.

In a randomized experiment context, the mean impact of a treatment on the treated group can be easily determined by measuring the difference between the mean values of the outcome variable for both the treatment and control groups [20]. However, those methods cannot be applied in our case because the rice farmers included in the sample were not randomly selected. Thus, an appropriate method to evaluate the impact requires identifying a comparison group and a treatment group based on similar characteristics. According to Caliendo and Kopeinig [21], PSM is a six-step mathematical procedure, as described in the following.

The main pillars of the study are the binary treatment T, which equals 1 if the irrigation facility is used and zero otherwise, and the potential outcome Y, which is defined as Y_i for the individual factors X_i. The average treatment effect for an individual farmer C_i or farmer D_i can be written as:

$$\begin{aligned} E[Y_i|T=1,\ X_i]- \quad & E[Y_i|T=0,\ X_i] \\ & = E[Y_{Ci}|T=1,\ X_i] - E[Y_{Di}|T=0,\ X_i] \\ & = E[Y_{Ci} - Y_{Di}|T=1,\ X_i] + E[Y_{Di}|T=1,\ X_i] - E[Y_{Di}|T=0,\ X_i] \\ & = E[Y_{Ci}|T=1,\ P(X_i)] - E[Y_{Di}|T=0,\ P(X_i)] \\ & = ATT \end{aligned} \quad (8)$$

The difference between $E[Y_{Di}|T=1,\ X_i]$ and $E[Y_{Di}|T=0,\ X_i]$ in the second line of Equation (8) is called “selection bias” because the outcomes of the individuals from the treatment and the comparison group would differ even in the absence of the treatment (Caliendo and Kopeinig [21]). However, the true parameter ATT (the average treatment on the treated) is identified as $E[Y_{Ci}|T=1,\ P(X_i)] - E[Y_{Di}|T=0,\ P(X_i)]$ in the third line of Equation (8).

To achieve a meaningful comparison between the treated and control groups, the two groups must be balanced. In this research, the balance was checked by comparing the standardized mean differences of each covariate. Most of them had been improved by the nearest neighbor matching technique (NNM), especially as the caliper was reduced from 0.25 to 0.10. According to Rosenbaum and Rubin [22], the mean standardized bias (the mean value of the standardized mean differences of all covariates) can be used as the corresponding values for the matched samples. Caliendo and Kopeinig [21] suggest that a mean standardized bias below 3% or 5% after matching may be considered as sufficient. In our results, the results of the matching satisfy this condition only when the NNM caliper = 0.10 (Table 6).

The differences in the mean values of the outcome variables for the treated and control groups were calculated for rice production area, rice production quantity, and rice production efficiency (Table 7). All estimates of the ATT are significant, and the impact of using the irrigation facility is negative for rice production area and rice production quantity, but positive for rice production efficiency. On the other hand, Inverse Probability Weighed Regression (IPWRA) is applied for covariate adjustment based on the biases from non-observable variables. The simulated values of ATE and Potential-Outcome mean (PO mean) for each outcome are depicted on Table 8. All estimates of simulated values are also significant as shown in the discussion in Table 7, and the impact of using the irrigation facility also can be confirmed and statistically derived.

Table 6. Test of balancing for covariates with standardized differences.

	Before Matching			NNM Caliper = 0.25			NNM Caliper = 0.10		
	Means Treated	Means Control	Std. Mean Diff.	Means Treated	Means Control	Std. Mean Diff.	Means Treated	Means Control	Std. Mean Diff.
Male labor between 15 and 55 years old	1.1604	1.3523	−0.244	1.1465	1.2777	−0.1668	1.2067	1.2580	−0.0652
Ethnicity	0.9807	0.6525	2.3877	0.9771	0.9771	0.0000	0.9750	0.9750	0.0000
Education	1.5091	1.1011	0.5681	1.4510	1.2662	0.2572	1.4078	1.3190	0.1236
Gender	0.8118	0.8339	−0.0565	0.8025	0.8191	−0.0423	0.8197	0.8294	−0.0248
Age of household head	2.7626	2.4494	0.2623	2.8191	2.6892	0.1088	2.7365	2.7240	0.0105
Non-agriculture income	0.3005	0.2343	0.1443	0.3032	0.2930	0.0222	0.3218	0.2968	0.0544
Total agriculture income	1.3690	1.4077	−0.0592	1.3936	1.4752	−0.1246	1.4438	1.4369	0.0106
Rate income from rice	0.6328	0.5701	0.1744	0.6229	0.6206	0.0064	0.6042	0.6240	−0.0550
All				935	1246		935	1246	
Matched				785	785		721	721	
Unmatched				141	429		205	493	
Discarded				9	32		9	32	

Source: Vietnamese Households Living Standards Survey 2016 (VHLSS 2016), n = 3444.

Table 7. Impact Evaluation for use of irrigation facility; before and after matching.

	Before Matching			NNM Caliper = 0.25			NNM Caliper = 0.10		
	Farmers Using Irrigation	Farmers Not Using Irrigation	Difference (*p*-Value)	Treated	Control	ATT (*p*-Value)	Treated	Control	ATT (*p*-Value)
Rice production area (sqm)	7432.3	11,004.9	−3572.7 (0.0000)	7835.4	13,532.1	−5696.7 (0.0000)	8387.8	12,742.7	−4354.8 (0.0000)
Rice production quantity (kg)	4601.8	6157.4	−1555.6 (0.0057)	4880.4	7674.7	−2794.2 (0.0001)	5279.7	7157.5	−1877.8 (0.0090)
Rice productivity of land (kg/sqm)	0.5583	0.5169	0.0413 (0.0000)	0.5563	0.5343	0.0221 (0.0000)	0.5614	0.5313	0.0301 (0.0000)

Source: Vietnamese Households Living Standards Survey 2016 (VHLSS 2016), n = 3444 and 2181.

Table 8. Impact Evaluation for use of irrigation facility; by extensive simulation augmented IP-WRA methods.

	Estimate	Standard Error	Z	P > |z|	95% Confidence Interval	
Rice Production Area (sqm)						
ATE	−4178.6	1157.5	−3.61	0.000	−6447.3	−1910.0
PO mean	11,239.0	477.8	23.52	0.000	10,302.6	12,175.4
Rice production quantity (kg)						
ATE	−1881.9	689.0	−2.73	0.006	−3232.3	−531.5
PO mean	6300.0	296.8	21.22	0.000	5718.2	6881.8
Rice productivity of land (kg/sqm)						
ATE	0.0303	0.0076	3.97	0.000	0.0154	0.0453
PO mean	0.5229	0.0041	128.18	0.000	0.5149	0.5309

Source: Vietnamese Households Living Standards Survey 2016 (VHLSS 2016), n = 2181.

In addition to these quantitative evaluations of these impacts, to certify these results in detail, further investigation into farmers' rice producing behaviors in Vietnam, such as case studies, is needed for farmers who do and do not use an irrigation facility. For example, the DEA model, fractional regression model, and some other kinds of approaches should be applied to evaluate production efficiencies with consideration to a variety of perspectives in our target area. For example, such an approach as meta-frontiers to assess productivity differences between adopters and non-adopters must be one of the most intriguing ones to be applied [23].

On the other hand, as in the case in Malaysia, discussed by Kangayatkarasu Nagulendran et al. [24], conservation priorities must be discussed in case we pursue economic development based upon the enlargement of agricultural production efficiencies in developing economies. Organic fertilizer choices especially can be one of the most crucial points for environmental conservation in these countries. These are also serious problems left for our future work.

4. Conclusions

This study explored the basic characteristics of Vietnamese rice producers and used SFA to find their rice production TE. The results demonstrate that Vietnamese rice farmers can be identified as small producers with limited land area whose cultivation might depend primarily on their experience. Furthermore, the household income revealed in this study has increased remarkably compared to the results reported in earlier studies. The average total value of farm earnings is about 78 million VND per year. However, farmers are currently devoting a great deal of attention to non-agricultural activities to gain higher incomes.

The estimation results of the stochastic frontier production function suggest that farmers can earn greater benefits when they grow mixed crops rather than using rice monoculture. The study also examined the important role of labor in TE. According to the results, labor has strongly affected TE. Farmers can optimize their TE by intensive investments in labor.

In their role of constructing a system, governments should encourage rice producers to seek higher efficiency in terms of optimizing mixed-crop cultivation. However, this study revealed that the use of organic fertilizers for rice production in Vietnam does not benefit households' TE. In the scope of this research, one could infer that self-provided organic fertilizers are of lower quality, but this supposition requires additional study.

Furthermore, this study has observed several issues related to rice production efficiency that are related to technical efficiency. We believe that it is especially important to acknowledge the fact that organic fertilizer has several important effects on harvesting rice, especially when farmers are using irrigation facilities. Due to the scope of this study, we are now conducting another study in order to draw more conclusions in relation to this study. Hence, in our next publication, we will suggest more implication policies related to this study.

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References

1. Asian Development Bank. Linking the Poor with Rice Value Chains. 2012. Available online: http://hdl.handle.net/11540/4363 (accessed on 10 May 2022).
2. Trung, N.D.; Thang, N.T.; Anh, l.; Babu, T.S.A.; Sebastian, L. Analysing the challenges in implementing Vietnam's Nationally-Determined Contribution (NDC) in the agriculture sector under the current legal, regulatory and policy environment. *Cogent Environ. Sci.* **2020**, *6*, 1792670. [CrossRef]
3. Badgley, C.; Moghtader, J.; Quintero, E.; Zakern, E.; Chappell, J.; Avilés-Vázquez, K.; Samulon, A.; Perfecto, I. Organic agriculture and the global food supply. Renew. *Agric. Food Syst.* **2007**, *22*, 86–108. [CrossRef]
4. Watkins, K.B.; Hristovska, T.; Mazzanti, R.; Wilson, C.E., Jr.; Schmidt, L. Measurement of technical, allocative, economic, and scale efficiency of rice production in Arkansas using data envelopment analysis. *J. Agr. Appl. Econ.* **2014**, *46*, 89–106. [CrossRef]
5. Boubacar, O.; Hui-qiu, A.; Rana, M.A.; Ghazanfar, S. Analysis on technical efficiency of rice farms and its influencing factors in south-western Niger. *J. Northeast. Agric. Univ.* **2016**, *23*, 66–77. [CrossRef]

6. Chandio, A.A.; Jiang, Y.; Gessesse, A.T.; Dunya, R. The nexus of agricultural credit, farm size and technical efficiency in Sindh, Pakistan: A stochastic production frontier approach. *J. Saudi Soc. Agr. Sci.* **2019**, *18*, 348–354. [CrossRef]
7. Kompas, T. *Market Reform, Productivity and Efficiency in Vietnamese Rice Production*; International and Development Economics Working Papers; Asia Pacific School of Economics and Government, Australian National University: Canberra, ACT, Australia, 2004.
8. Giang, T.N.D. An Analysis of the Technical Efficiency of Crop Farms in the Northern Region of Vietnam. Ph.D. Thesis, University of Canberra, Canberra, ACT, Australia, 2013. [CrossRef]
9. Khai, H.; Yabe, M. Technical efficiency analysis of rice production in Vietnam. *J. Int. Soc. SE Asian Agr. Sci.* **2011**, *17*, 135–146.
10. Aigner, D.; Lovell, C.K.; Schmidt, P. Formulation and estimation of stochastic frontier production function models. *J. Econom.* **1977**, *6*, 21–37. [CrossRef]
11. Meeusen, W.; van den Broeck, J. Technical efficiency and dimension of the firm: Some results on the use of frontier production functions. *Empir. Econ.* **1977**, *2*, 109–122. [CrossRef]
12. Aigner, D.J.; Chu, S.F. On estimating the industry production function. *Am. Econ. Rev.* **1968**, *58*, 826–839.
13. Timmer, C.P. Using a probabilistic frontier production function to measure technical efficiency. *J. Polit. Econ.* **1971**, *79*, 776–794. [CrossRef]
14. Afriat, S.N. Efficiency estimation of production functions. *Int. Econ. Rev.* **1972**, *13*, 568–598. [CrossRef]
15. Richmond, J. Estimating the efficiency of production. *Int. Econ. Rev.* **1974**, *15*, 515–521. [CrossRef]
16. Schmidt, P. On the statistical estimation of parametric frontier production functions. *Rev. Econ. Stat.* **1976**, *58*, 238–239. [CrossRef]
17. Battese, G.; Coelli, T. Frontier production functions, technical efficiency and panel data: With application to paddy farmers in India. *J. Prod. Anal.* **1992**, *3*, 153–169. [CrossRef]
18. Le Ngoc, H. Contract farming effects on technical efficiency of the export-oriented rice production sector in Vietnam. In Proceedings of the 2018 Conference of International Association of Agricultural Economists (IAAE), Vancouver, BC, USA, 28 July–2 August 2008.
19. Nguyen, H.-T.-M.; Do, H.; Kompas, T. Economic efficiency versus social equity: The productivity challenge for rice production in a 'greying' rural Vietnam. *World Dev.* **2021**, *148*, 105658. [CrossRef]
20. Van Ho, B.; Nanseki, T.; Chomei, Y. Profit efficiency of tea farmers: Case study of safe and conventional farms in northern Vietnam. *Environ. Dev. Sustain.* **2019**, *21*, 1695–1713. [CrossRef]
21. Caliendo, M.; Kopeinig, S. Some practical guidance for the implementation of propensity score matching. *J. Econ. Surv.* **2008**, *22*, 31–72. [CrossRef]
22. Rosenbaum, P.; Rubin, D.B. Constructing a control group using multivariate matched sampling methods that incorporate the propensity score. *Am. Stat.* **1985**, *39*, 33–38. [CrossRef]
23. Villano, R.; Bravo-Ureta, B.E.; Solís, D.; Fleming, E. Modern Rice Technologies and Productivity in the Philippines: Disentangling Technology from Managerial Gaps. *J. Agri. Econ.* **2015**, *66*, 129–154. [CrossRef]
24. Nagulendran, K.; Padfield, R.; Aziz, S.A.; Amir, A.A.; Abd Rahman, A.R.; Latiff, M.A.; Zafir, A.; Quilter, A.G.; Tan, A.; Arifah, S.; et al. A multi-stakeholder strategy to identify conservation priorities in Peninsular Malaysia. *Cogent Environ. Sci.* **2016**, *2*, 1254078. [CrossRef]