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TECHNICAL AND RESOURCE USED EFFICIENCY OF RICE PRODUCTION IN THE MEKONG DELTA, VIETNAM

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Abstract

This study aims at evaluating the technical efficiency and resource use efficiency in rice production in the Mekong Delta. This study used a parametric estimation method through the stochastic frontier production function under the translog form, and was performed using software Frontier 4.1. The research data is the Winter-Spring season – one of the main crops in rice production in this region and in the 2017 – 2018 crop year. The results show that the technical efficiency is 91.5%; and a fraction of one quarter of households has still technical efficiency below 90%. Besides, the efficiency of using input resources is not optimal. Many types of materials such as seeds, fertilizers, and pesticides have been used in an excess of the necessary and recommended levels of the agricultural agency. The farm-size is not too large, but it is possible that because there are many farm plots, which also adversely affect the technical efficiency and the resource use efficiency. Positive factors that increase technical efficiency need to be focused on for replication such as educational level, production experience, participation in technical training classes, contract farming. This study is expected to have policy implications for rice production in the Mekong Delta in the near future.

Key words*: *Mekong Delta, resource use efficiency, rice production, stochastic frontier production function, technical efficiency

INTRODUCTION

The Mekong Delta has a natural area of about 4 million hectares, of which nearly 1.7 million hectares are used for rice production, being a key rice production area of Vietnam and one of the few largest rice-producing deltas in the world [7, 12, 3, 37]. Rice in this area is intensively cultivated. There are more than a million small-scale rice farmers in the region who also have long experience in rice farming. Nonetheless, the intensive farming in associating with long experience of rice farming has not identically meant that rice is technically cultivated as well as the resource used for rice is fully efficient.

As being the third world's largest rice exporter, the region's rice production and productivity has increased overtime [13], however, the doses of fertilizer and agro-chemical used for rice also increased pararelly [31, 33]. In addition, the rate of the technical package adoption like 1M5R (One Must Do Five Reductions), 3G3R (3 Gains 3 Reductions) as well as the standardization of products like SRP (Sustainable Rice Platform), VietGAP (Vietnam Good Agriculture Practice), Global GAP (Global Good Agriculture Practice), etc., are also limited despite many state and NGOs technical supports are already given [18, 29]. This implies that inefficiency of resource use in the rice farming might have existed in the region.

The resource use efficiency as well as the technical efficiency is an important concept in economic performances of an agricultural firm. The technical efficiency has been widely studied in agriculture. It was initially proposed by Coelli (1995) [9] which referred to the firm that is more efficiency than the others once its productivity is further enhanced by how input factors are combined and transformed into a higher amount of outputs with the same amount of inputs and technological level applied. Two approaches of the parametric stochastic frontier analysis (SFA) proposed by Aigner et al. (1977) [2], Meeusen and Van den Broeck (1977) [26] and the nonparametric Data Envelopment Analysis (DEA) developed by Charnes et al. (1978) [8] are able to measure the technical efficiency. Each approach has its own advantages and limitations, so that the choice of which approach for use depends on the research objective, type of industry as well as the availability of data [38]. The DEA approach does not need to establish a production function of the firm under observation, nonetheless, DEA fails to take into consideration the possible impact of random shock like measurement error and other types of noise in the data [9, 20, 38] as cited by Ahmadzai and Hayatullah (2017) [1]. Contrarily, the parametric approach with a construction of stochastic production frontier function that is widely used to measure both the level of firm efficiency and error term to captures technical inefficiency across production units [21]. It is therefore the SFA overcomes the limitations of the above DEA approach [1]. Significantly, the stochastic frontier function is able to represent a best-practice technology against which the efficiency of firms within the industry can be measured [9].

The Mekong Delta is formerly considered a favorable region for rice production [15, 32] though recently there always exists number of natural uncertainties affecting rice production, especially they appear much more often in the context of recent climate change. Extreme events of droughts, inundations and abnormal rains are much frequently occurred [36, 34]. Such the stochastic effects are considered as errors beyond the control of the rice farmers; and they need to be measured and isolated from the other deviation causing technical inefficiency. Since this study focuses on assessing the level of technical efficiency as well as technical inefficiencies, and at the same time identifies the factors induced by production units that affected technical inefficiencies, the SFA parametric method is therefore employed. This study will furtherly examine the economic efficiency of key resource inputs such as seed, fertilizer, pesticide, labour, etc. The research findings are expected to be a scientific basic for policy implications.

MATERIALS AND METHODS

Study area and data collection

Rice is a crop that shares largest area in total agricultural land of the delta. This study selected five provinces located in the upper and middle areas of the delta where rice is dominantly and intensively cultivated, including (1) Dong Thap, (2) An Giang, (3) Can Tho, (4) Hau Giang and (5) Soc Trang (Figure 1).

The total surveyed households are 470, spreading relatively evenly over these five provinces, and corresponding to 90 to 100 households for each province. The samples were selected in three stages, firstly by purposive stratification that is, in the intensive rice cultivation area as in the five targeted provinces, secondly, by selecting rice producing with cooperatives, and finally random selection of rice farmers consisting of equal respondents inside and outside of the cooperative on the same adjacent areas. Observational sampling like this is intended to find out how cooperatives affect the technical efficiency and resource use efficiency.

The survey was conducted in 2018; and the data was collected in the Winter-Spring 2017-2018, which is a main seasonal rice crop in the region. The collected data includes demographic characteristics of farmers, technical characteristics applied and economic achieved for each crop. All these features are exploited to serve as inputs for the stochastic frontier production function models as well as the resource use efficiency analysis later in this study.

Analytical methods

This study uses the parametric estimation method by applying the stochastic frontier production function [2, 5, 26]. The estimation method has been widely applied for a vast number of studies in agriculture, particularly adequate for small-scale farm units [6, 25, 28, 1, 23]. The generic form of the function is as follow:

$$Y_i = f(X, B) + e_i \qquad (1)$$

where: Y_i refers to the total rice output of the i^{th} farm measured in kg, f(X,B) is a production function of the vector of inputs X, B refers to vector of parameters to be estimated, and e_i

refers to an error term. The error term in the stochastic frontier production function has two components, which is expressed as follow:

$$e_i = V_i + U_i \qquad (2)$$

where :V_i is an identically and independently normally random error [$V \sim N(0,\delta_V^2)$] that captures the stochastic effects beyon the farmers control; U_i is a one-sided efficiency component that captures the technical inefficiency of the farmer. V_i and U_i are assumed to be the normal and half-normal distributed, respectively.

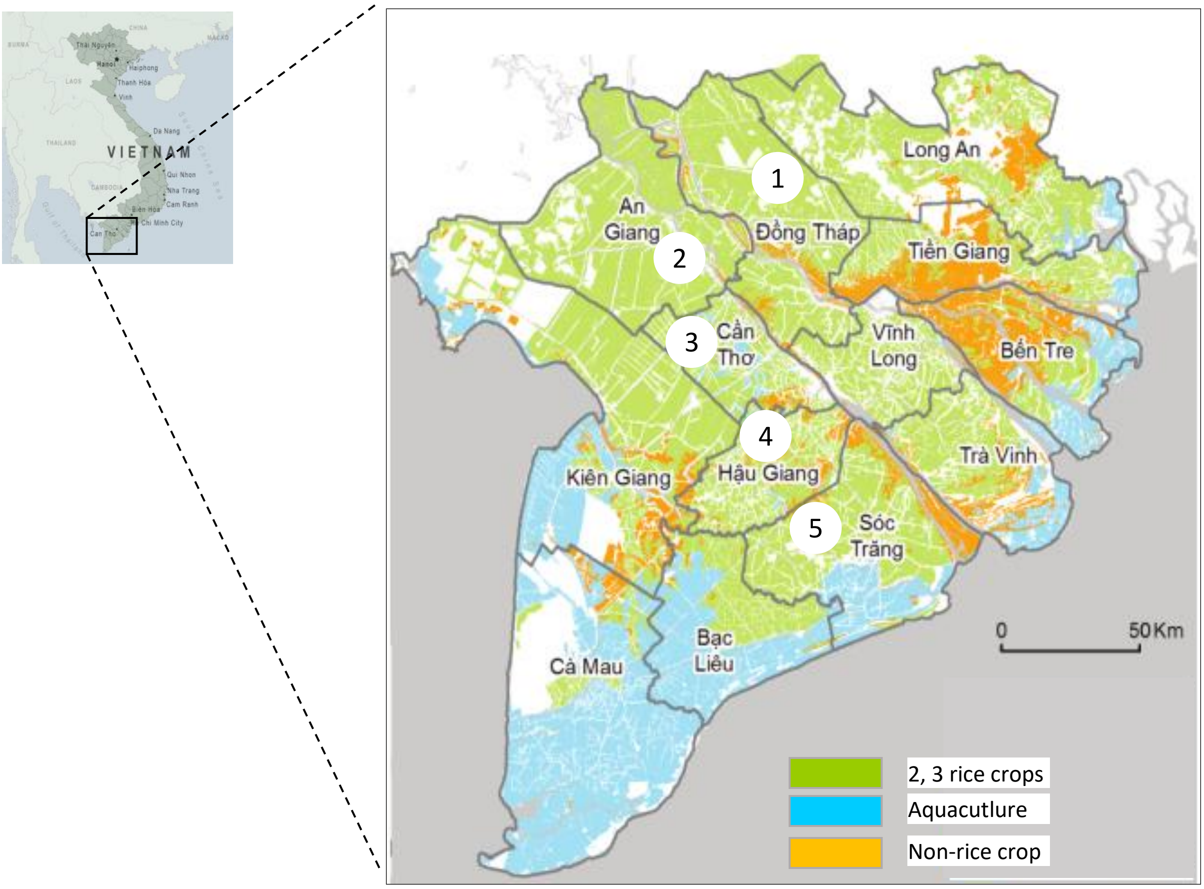

Fig. 1. Relative location of the surveyed sites in the Mekong Delta
Source: Adapted from Chapman et al. (2017).

The technical efficiency of the i^{th} farm is estimated by the ratio of the observed output (Y_i) to maximum possible output (Y_i^*) derived by the stochastic frontier function estimation. The technical efficiency estimation is expressed as follow:

$$TE = \frac{Y_i}{Y_i^*} = \frac{\exp(X_i B)\exp(V - U)}{\exp(X_i B)\exp(V)}$$

or

$$TE = \exp(-U) \qquad (3)$$

So that 0<TE<1;

The equations (1) is written and estimated either by Cobb-Douglas or translog form depending on result of the test of Generalized Livelihood Ratio. For the Cobb-Douglas form, it is written as the (4) as follow:

$$\ln(yield_i) = \beta_0 + \beta_1 \ln(seed_i) + \beta_2 \ln(fertilizer_i) + \beta_3 \ln(pesticide_i) + \beta_4 \ln(labour_i) + \beta_5 \ln(land_i) + (V_i - U_i)$$

For the Translog form, it is written as the (5) as follows:

$$\ln(yield_i) = \beta_0 + \beta_1 \ln(seed_i) + \beta_2 \ln(fertilizer_i) + \beta_3 \ln(pesticide_i) + \beta_4 \ln(labour_i) + \beta_5 \ln(land_i) +$$
$$\frac{1}{2}\beta_{11} \ln(seed_i)^2 + \frac{1}{2}\beta_{22} \ln(fertilizer_i)^2 + \frac{1}{2}\beta_{33} \ln(pesticide_i)^2 + \frac{1}{2}\beta_{44} \ln(labour_i)^2 + \frac{1}{2}\beta_{55} \ln(land_i)^2$$
$$+ \beta_{12} \ln(seed_i)\ln(fertilizer_i) + \beta_{13} \ln(seed_i)\ln(pesticide_i) + \beta_{14} \ln(seed_i)\ln(labour_i)$$
$$+ \beta_{15} \ln(seed_i)\ln(land_i) + \beta_{23} \ln(fertilizer_i)\ln(pesticide_i) + \beta_{24} \ln(fertilizer_i)\ln(labour_i)$$
$$+ \beta_{25} \ln(fertilizer_i)\ln(land_i) + \beta_{34} \ln(pesticide_i)\ln(labour_i) + \beta_{35} \ln(pesticide_i)\ln(land_i)$$
$$+ \beta_{45} \ln(labour_i)\ln(land_i) + (V_i - U_i)$$

where:
yield is the rice output per hectare (kg/ha), β_0, … β_4 are parameters to be estimated, seed is amount of seed sown per hectare (kg/ha), fertilizer is dose of fertilizer applied per hectare (kg/ha), pesticide is cost per hectare (1,000 VND/ha), labour is the number of manday worked per hectare (manday/ha), and land is the size of rice land (ha). All of these inputs and output are collected for the main cropping season, namely Winter-Spring (spans from December 2017 to March 2018).
The technical inefficiency determinants are specified as follow:

$$U_i = \alpha_0 + \alpha_i \sum_{1}^{9} Z_i + \varepsilon_i \qquad (5)$$

where:
U_i is technical inefficiency, α_0, …, α_i are the parameters to be estimated; Z_i is a vector of exogenous variables that are likely to affect efficiency, α's are the parameters to be estimated, and ε_i is the random error term. As the dependent variable in equation (5) is defined in terms of technical inefficiency, a farm-specific variable associated with the negative (positive) coefficient will have a positive (negative) impact on technical efficiency.
The pamameters of both functional models expressed by (4) and (5) are joinly estimated by the maximum likelihood method, using Frontier 4.1, and a half-normal distribution of the inefficiency variance was used in the estimation [10].

Estimation of economic efficiency of resource use

Economically, the profit maximization principle states that a firm reaches its profit maximum as long as it keeps its operation at the level where the marginal cost is equal to marginal revenue, in other words, at the point of the firm profit maximization the efficiency of using input resources is optimal. This principle is true for firms that use multi-input factors such as in agriculture, and they are used in this study. Economic efficiency of resource used of a firm is reached an optimal point as long as the marginal value product (MVP) is equal to their marginal factor cost (MFC) under perfect competition. The economic efficiency parameter is hence calculated by using the ratio of MVP of inputs to the MFC. This principle has been applied in many studies [14, 16, 4, 19].

$$r = \frac{MVP}{MFC}$$

where:
r = efficient ratio
MVP_i = marginal value of product of the ith input
MFP_i = marginal factor cost of the ith input

$$MVP_i = \beta_i \frac{\bar{Y}}{\bar{X}_i}.P_y$$

$\bar{Y}$ = Geometric mean of the value of output
$\bar{X}_i$ = Geometric mean of the ith input
β_i = estimated coefficient (elasticity) of the ith input, derived from the function (Eq.4),
P_y = price of output
To decide whether or not an input is used efficiently, the following rules is applied:
r = 1, it implies the input was used efficiently;
r > 1, it implies the input was underutilized and increased utilization will increase output.
r < 1, it implies the resource is over utilized and reduction in its usage would lead to maximization of profit.

The relative percentage change in MVP (Marginal value product adjustment) of each resource required in order to obtain optimal allocation of resources. i.e. r = 1 or MVP = MFC which was estimated using equation below [27].

$$D = (1 - \frac{MFC}{MVP}) * 100 \text{ or } D = (1 - \frac{1}{r}) * 100$$

where:
D = absolute value of percentage change in MVP of each resource.

RESULTS AND DISCUSSIONS

Demographic and farm-specific characteristics

Table 1 presents the values of the variables used in the stochastic frontier production function, and shows the demographic and social economic characteristics of rice-producing households in the Mekong Delta. First of all, rice farmers usually have a fairly old age, averaging 50.4 years, which also entails a very high rice farming experience of nearly 25 years, and most of them are male. Like many other studies, the educational level of farmers is relatively low, only about 6.7 years of schooling, which is likely consistent with other studies in the region [17, 35]. Thanks to the agricultural extension policy implemented over the years [17, 11], up to 74% of farmers have attended training courses on rice cultivation techniques.

Farmers in the Mekong Delta often buy inputs for production at material agents that are available in the countryside and are very convenient. Most of them buy materials and pay after harvest at the end of the crop without necessarily paying at the time of purchase, so they don't need much initial investment; access to loans mainly for rice production is not popular. In this study, only 22% of households have loans and 16% of households pay cash directly when buying materials.

Table 1. Descriptive statistics of variables in stochastic frontier production function model

Variables	Min.	Max.	Mean	Std.
(Y) Yield (kg/ha)	4,000	11,800	7,776	1,185
(Z_1) Age of head (year)	24.0	87.0	50.4	11.3
(Z_2) Gender (1-Male; 0- Female)			0.88	
(Z_3) Experience (year)	2.0	70.0	24.9	11.4
(Z_4) Education (year)	0.0	16.0	6.7	3.4
(Z_5) Training (1-Yes; 0-No)			0.74	
(Z_6) Loan accessed (1-Yes; 0-No)			0.22	
(Z_7) Sell to company (1-Yes; 0-No)			0.13	
(Z_8) Input payment (1-direct; 0-No)			0.16	
(Z_9) Coop. member (1-Yes; 0-No)			0.51	
(X_1) Seed (kg/ha)	93.30	390.00	176.86	47.62
(X_2) Fertilizer (kg/ha)	64.00	688.30	249.50	76.91
(X_3) Pesticide cost(10^3 VND/ha)	68.80	2,165	653.03	329.15
(X_4) Labour (day/ha)	0.60	64.00	13.78	9.29
(X_5) Land (1,000m^2)	1.30	208.00	21.35	23.13

Source: Author's calculation.

Besides, sales of rice products to consumption companies account for a low rate of only 13% as it depends on how well contract farming is built, which is also consistent with other studies [22, 12].

Rice yield is relatively high at 7,776 tons/ha, however the inputs are also high. The average amount of seed used is 176 kg/ha, which is higher than recommended by the agricultural authority [11]. The average amount of fertilizer used was 249 kg/ha, which is the amount of pure NPK fertilizer calculated from commercial fertilizers used by farmers. The amount of pure fertilizer used is much higher than recommended by the agricultural authority [11]. For pesticides, they are calculated by the cost used instead of the quantity, because in fact there are many types of pesticides with very different and complex active ingredients and concentrations. The survey results show that on average, each hectare has cost 653 thousand VND, which is also quite a high expenditure [17].

In fact, in the Mekong Delta, most rice production in the field is mechanized, especially in the stages of land preparation and harvesting [30]. The stages are also done manually or a combination of manual and mechanization is fertilizing and spraying pesticides. Farmers often use manual labor for re-transplanting, weeding and field management, so only about 14 mandays are used. Another feature is that the land area is also shown in Table 1, in which the average farm-size is 2.135 ha per household. This is the total farm-size and it can be split more than one plots of land [24], although the plots may be located in close proximity to each other in the same locality.

Determinants of technical efficiency and resource use

To get the estimated result, the Generalized Livelihood Ratio test is firstly performed and shows that the index $\lambda = - 2 \{\log [L(H_0) - \log[L(H_1)]\} = 32.404$, where, L (H_0) is the log-likelihood value of the Cobb-Douglas model as the (4) and $L(H_1)$ is the log-likelihood value of the translog model as the (5) above, is larger than the critical value (λ_{table} = 24.996; df=15), so the translog model considered appropriated for further estimation of the stochastic frontier production function.

Accordingly, the stochastic frontier production function under translog form is estimated by the Maximum Livelihood method using the Frontier 4.1 program. The estimated value of σ^2 is positive and 0.120, which is statistically significant at 1% level. These values indicate that there exists sufficient evidence to suggest that technical inefficiencies are present in the data and that the differences between the observed (actual) and frontier (potential) output are due to inefficiency. These imply that the estimated model and distributional assumptions for the error terms are appropriate (Table 2).

Table 2. Maximum Livelihood Estimates of the stochastic frontier production function model

	Coefficient	**SE**	**t-ratio**
β_0 (Constant)	14.988***	1.181	12.695
(X_1) Ln seed (kg/ha)	-0.620	0.599	-1.035
(X_2) Ln fertlizer (kg/ha)	-0.681*	0.520	-1.308
(X_3) Ln pesticide (10^3 VND/ha)	-0.694**	0.346	-2.008
(X_4) Ln labour (day/ha)	0.059	0.292	0.201
(X_5) Ln land (1,000m^2)	-0.489***	0.207	-2.361
½ *Ln $(X_1)^2$	-0.326**	0.181	-1.805
½ *Ln $(X_2)^2$	-0.094	0.101	-0.925
½ *Ln $(X_3)^2$	0.058*	0.042	1.375
½ *Ln $(X_4)^2$	0.059***	0.024	2.418
½ *Ln $(X_5)^2$	0.022*	0.015	1.465
Ln (X_1)*Ln (X_2)	0.240***	0.096	2.501
Ln (X_1)*Ln (X_3)	0.117**	0.066	1.781
Ln (X_1)*Ln (X_4)	0.032	0.049	0.650
Ln (X_1)*Ln (X_5)	0.089***	0.035	2.509
Ln (X_2)*Ln (X_3)	-0.006	0.047	-0.128
Ln (X_2)*Ln (X_4)	-0.017	0.035	-0.486
Ln (X_2)*Ln (X_5)	0.021	0.029	0.714
Ln (X_3)*Ln (X_4)	-0.053**	0.024	-2.206
Ln (X_3)*Ln (X_5)	-0.035**	0.019	-1.892
Ln (X_4) *Ln (X_5)	0.027**	0.016	1.735
Sigma square (σ^2)	0.113***	0.038	2.988
Gamma (γ)	0.883***	0.031	27.721
Log-likelihood:	247.404		
Observations (N):	470		
LR test:	51.343		

***: $p<0.01$; **: $p<0.05$; *: $p<0.1$

Source: Author's calculation.

The estimated results also show that the gamma (Υ) value is 0.893 (~1), which indicates that technical inefficiency is existing in the production [5, 9]. Specifically, rice production in the Mekong Delta is suffering from a certain rate of inefficiency due to household characteristics and other socio-economic factors.

Estimation results show that input variables such as fertilizers, pesticides have a negative and statistically significant effect on yield. These two types of materials have been used almost beyond the necessary threshold compared to the needs of rice and are also reflected in previous studies [17, 11, 31, 33, 29, 18].

The average farm-size is 2.135 ha, but in some cases up to 2.313 ha, in addition, the farm-size often has more than one parcel of land, making it difficult to manage and take care of. In this study, farm-size hence had a negative effect on productivity.

Meanwhile, seed quantity and labor had no significant impact on yield. In addition, the variable squares and variable interactions also have certain effects on rice yield (Table 2).

The level of technical efficiency averaged of 91.5%, which is quite high (Table 3). However, there is still a certain percentage of farm households with low technical efficiency, in which the ranges of 50 – 60%, >60 – 70%, >70 – 80% and >80 – 90% reach a frequency of 0.64%, 0.85%, 4.26% and 17.45%, respectively.

The majority of farmers (76.81%) achieved technical efficiency levels from over 80 to 90%. The technical efficiency level reached in the current study is much higher than that found by Ho and Shimada (2019) [17].

There are many factors affecting technical efficiency in rice production.

Table 3. Distribution of technical efficiency

Level of technical efficiency	**Frequency**	**Percentage**
0.0-<0.5	0	0.00
0.5-<0.6	3	0.64
0.6-<0.7	4	0.85
0.7-<0.8	20	4.26
0.8-<0.9	82	17.45
0.9-<1.0	361	76.81
1.0	0	0.00
Observation	470	
Min	0.525	
Max	0.977	
Mean	0.915	
Std.	0.061	

Source: Author's calculation.

A number of demographic parameters and technical factors affecting technical inefficiency as shown in Table 4, in which a positive sign of co-efficiency has a positive effect on technical inefficiency, which means it has a negative effect on technical efficiency, and vice versa.

The test results show that the age and male sex factors of the household head have an impact on increasing technical inefficiency. This can happen in the elderly, they often have difficulty in accessing and applying new science and technology, or they are also somewhat conservative in the application of new technology. Besides, the elderly farmers are mostly male, so the male gender phenomenon also increases technical inefficiency.

Table 4. Determinants of technical inefficiency in rice production

	Coefficient	**SE**	**t-ratio**
α_0 (Constant)	-0.685**	0.404	-1.695
Z_1 Age of head	0.017***	0.007	2.455
Z_2 Gender (1-Male; 0- Female)	0.159**	0.093	1.713
Z_3 Experience (year)	-0.018***	0.007	-2.510
Z_4 Education (year)	-0.075**	0.036	-2.067
Z_5 Training (1-Yes; 0-No)	-0.319***	0.121	-2.648
Z_6 Loan accessed (1-Yes; 0-No)	0.038	0.049	0.779
Z_7 Sell to company (1-Yes; 0-No)	-0.371***	0.111	-3.328
Z_8 Input payment (1-direct; 0-No)	-0.825***	0.345	-2.388
Z_9 Coop. member (1-Yes; 0-No)	-0.038	0.054	-0.716

***: $p<0.01$; **: $p<0.05$; *: $p<0.1$.

Source: Author's calculation.

Factors that negatively affect technical inefficiency are synonymous with positive effects on technical efficiency such as experience, education, and training. These are factors that can easily see their effects in the application of new techniques to rice production. Besides, selling rice to the company also increases the technical efficiency, this happens because when farmers sell rice to the company, it means that they have done contract farming with the company, and at the same time they used the techniques and production processes offered by the company and they increased technical efficiency. Similarly, households that pay cash directly to agents when they buy materials often have financial viability as well as factors of good technology acquisition, which also positively affect the technical efficiency.

Resource use efficiency

Resource use efficiency of different inputs for rice production was determined based on the ratio value (r) of the marginal value of product over marginal cost of each input as showed in Table 5. Overally, the r value of four inputs of seed, fertilizer, pesticides and land size are negative and less than 1, thus these input factors have over-utilized. These indicate the fact that these inputs are being used to an extent that any increase in their uses brings about a decrease in output. Particularly for labor, the r value is almost equal 1, which indicates that the labor input is used at efficient level. Thus, in order to reach efficient level, the input factors such as seed, fertilizer, pesticides and land size should be reduced by an extend of 108.14%, 108.16%, 102.16% and 210.26%, respectively as showed in the last column of Table 5.

Table 5. Resource Use Efficiency

Variables	β_i	MPP_i	$MVP_i = MPP_i*Py$	MFC (VND)	r=MVP/MFC	Decision Rule	D= (1-1/r) *100
Seed	-0.62	-27.26	-152,471	12409	-12.29	overutilized	108.14
Fertilizer	-0.681	-21.23	-118,714	9687	-12.26	overutilized	108.16
Pesticide	-0.694	-8.26	-46,225	1000	-46.22	overutilized	102.16
Labour	0.059	33.30	186,221	178362	1.04	~ Efficient	4.22
Land	-0.489	-178.11	-996,179	1,098,400	-0.91	overutilized	210.26

Source: Author's calculation.

The statistical results described in Table 1 as well as the above estimation results show that the majority of rice farmers in the Mekong Delta have long experience but also come with traditional practices, using excessive input materials, negatively affecting technical efficiency as well as resource use efficiency. Many agricultural extension programs with many new forms of technology transfer reach farmers and have certain positive impacts, but are not widespread. One of the reasons for this slowdown is that the rate of production implementation in the form of contract farming and value chain linkage has not been replicated.

The percentage of farmers participating in cooperatives is also limited. Therefore, upcoming policies should focus on these solutions to improve the technical efficiency and resource use efficiency in rice production.

CONCLUSIONS

Rice is the most common and widely cultivated in the Mekong Delta. Rice production reaches a very big quantity and that plays an important role in ensuring the national food security and export. However, the technical efficiency in rice production is not completely optimal, only 91.5%, and a proportion of about 25% of households have their technical efficiency less than 90%. The ratio of resource use efficiency of several inputs such as seed quantity, fertilizer dose, pesticide expenditure and farm-size are being negative because they are used excessively or beyond the ability of farmers to manage.

Besides the negative impacts caused by elder age and traditional customs that the farmers applied, there are a number of socio-economic environmental factors that positively affect the technical efficiency and resource use efficiency, such as participation in technical training courses, cooperatives membership, contract farming, etc., ... For further improving the technical efficiency and resource use efficiency in rice production, policies related to promoting farmers to better implement the above positive measures are really necessary.

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REFERENCES

[1]Ahmadzai, H., 2017, Crop diversification and technical efficiency in Afghanistan: Stochastic frontier analysis, CREDIT Research Paper, No. 17/04, The University of Nottingham, Centre for Research in Economic Development and International Trade (CREDIT), Nottingham

[2]Aigner, D., Lovell, C.K., Schmidt, P., 1977, Formulation and estimation of stochastic frontier production function models. J. of Econometrics. 6, 21–37.

[3]Anthony, E.J., Brunier, G., Besset, M., Goichot, M., Dussouillez, P., Nguyen, V.L., 2015, Linking rapid erosion of the Mekong River delta to human activities. Scientific Reports. 5:14745 | DOi: 10.1038/srep14745, Accessed on ????

[4]Awunyo, V. D, Wongnaa, C.A., Aidoo, R., 2016, Resource use efficiency among maize farmers in Ghana. Agric & Food Secur, 5:28. DOI 10.1186/s40066‑016‑0076‑2, Accessed on Sep. 24th, 2021

[5]Battese, G.E., Corra, G.S., 1977, Estimation of a production frontier model: with application to the pastoral zone of Eastern Australia, Australian Journal of Agricultural Economics 21(3), 169–179.

[6]Binam, J.N., Tonye, J., Nyambi, G., Akoa, M., 2004, Factors affecting the technical efficiency among smallholder farmers in the slash and burn agriculture zone of Cameroon. Food policy, 29(5), 531-545.

[7]Chapman, A., Darby, S., Tompkin, E., Hackney, C., Leyland, J., Van, P.D.T., Pham, T.V., Parson, D., Aalto, R., Nicholas, A., 2017, Sustainable rice cultivation in the deep flooded zones of the Vietnamese Mekong Delta. Life sciences agriculture. Vol.59, No.2.

[8]Charnes, A., Cooper, W.W., Rhodes, E., 1978, Measuring the efficiency of decision making units. European J. of Operational Research. 2, 429–444.

[9]Coelli, T.J., 1995, Recent developments in frontier modelling and efficiency measurement. Australian Journal of Agricultural Economics. Vol.39, No.3. pp 219-245.

[10]Coelli, T.J., 1997, A guide to Frontier version 4.1: A Computer Program for Stochastic Frontier Production and Cost Function Estimation. CEPA Working Paper.

[11]Connor, M., Tuan, A.L., Deguia, A.H., Wehmeyer, H., 2020, Sustainable rice production in the Mekong River Delta: Factors influencing farmers' adoption of the integrated technology package "One Must Do, Five Reductions" (1M5R). Outlook on Agriculture. 2021; 50 (1): 90-104. doi: 10.1177/0030727020960165, Accessed on November 01st, 2021

[12]Dung, L.C., Son, N.P., Tuan, V.V., Thoa and Eiligmann, A., 2021, The Rice Value Chain in the Mekong Delta, Viet Nam. GIZ funded project's report.

[13]FAOSTAT, 2021, Commodities by country. https://www.fao.org/faostat/en/#compare, Accessed on October, 29th, 2021.

[14]Fasasi, A.R., 2006, Resource use efficiency in yam production in Ondo State, Nigeria. Agricultural Journal, 1(2): 36–40.

[15]Global Rice Science Partnership, GRISP, 2013, Rice almanac. International Rice Research Institute. https://doi.org/10.1093/aob/mcg189, Accessed on November 01st, 2021

[16]Goni, M., Mohammed, S., Baba, B.A. 2007, Analysis of resource use efficiency in rice production in the Lake Chad area of Borno State, Nigeria. Journal of Sustainable Development in Agriculture and Environment, 3(2), 31–37.

[17]Ho, T.T., Shimada, K., 2019, Technical Efficiency of Rice Farming in the Vietnamese Mekong Delta: A Stochastic Frontier Approach. The Ritsumeikan Economic Review, Vol. 67 No.5.6.

[18]Huan, N.V., Thiet, L.V., Chien, L.V., Heong, K.L., 2005, Farmers' participatory evaluation of reducing pesticides, fertilizers and seed rates in rice farming in the Mekong Delta. Vietnam. Crop Prot. 24, 457–464. doi: 10.1016/j.cropro.2004.09.013, Accessed on November 4th, 2021

[19]Karthick, V., Alagumani, T., Amarnath, J. S., 2013, Resource–use Efficiency and Technical Efficiency of Turmeric Production in Tamil Nadu — A Stochastic Frontier Approach. Agricultural Economics Research Review. Vol. 26(1):109-114.

[20]Kumbhakar, S.C., Lovell, C.A.K., 2000, Stochastic Frontier Analysis. Cambridge University Press.

[21]Liu, Y., 2006, Model Selection in Stochastic Frontier Analysis: Maize Production in Kenya. Department of Agricultural Economics and Department of Economics Michigan State University. Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Long Beach, California, July 23-26, 2006. PhD Dissertation Chapter 2.

[22]Loc, V.T.T., Son, N.P., 2013, Rice value chain in the Mekong Delta, Vietnam: solutions for rice value added improvement and sustainable development. CAS Discussion paper No 93. Centre for ASEAN Studies and Centre for International Management and Development Antwerp.

[23]Mango, N., Makate, C., Hanyani-Mlambo, B., Siziba, S., Lundy, M., 2015, A stochastic frontier analysis of technical efficiency in smallholder maize

production in Zimbabwe: The post-fast-track land reform outlook, Cogent Economics & Finance, Taylor & Francis, Abingdon, Vol. 3, Iss. 1, pp. 1-14, http://dx.doi.org/10.1080/23322039.2015.1117189, Accessed on September 24th, 2021

[24]Matsubara, T., Truong, C.T., Dung, L.C., Kitaya, Y., Maeda, Y., 2020, Transition of Agricultural Mechanization, Agricultural Economy, Government Policy and Environmental Movement Related to Rice Production in the Mekong Delta, Vietnam after 2010. AgriEngineering 2020, 2, 649–675; doi:10.3390/agriengineering2040043, Accessed on August 10th, 2021

[25]Mazvimavi, K., Ndlovu, P.V., An, H., Murendo, C., 2012, Productivity and efficiency analysis of maize under conservation agriculture in Zimbabwe. Paper presented at the International Association of Agricultural Economics (IAAE) Triennial Conference, Foz do Iguaçu. http://dx.doi.org/10.1016/S0305-750X(99)00116-3, Accessed on Novemer 5th, 2021

[26]Meeusen, W., Van, D.B., 1977, Efficiency estimation from Cobb-Douglas production functions with composed error. Int. Economic Review. 435–444.

[27]Mijindad, N.B., 1980, Production efficiency on farms in northern Nigeria. PhD dissertation. Cornell University, USA.

[28]Mochebelele, M.T., Winter-Nelson, A., 2000, Migrant labor and farm technical efficiency in Lesotho. World Development, 28, 143–153.

[29]Phung, N.T.M., Du, P.V., Singleton, G., 2014, One Must Do, Five Reductions (1M5R): Best Management Practices for Lowland Irrigated Rice in the Mekong Delta. Ministry of Agricultural and Rural Development: Vietnam and International Rice Research Institute, Philippines.

[30]Sakata, S., 2020, The Mechanization of Rice Production in Vietnam: An Analysis of Lifecycle of Agricultural Machinery. Sakata, Shozo ed. 2020. Structural Changes of Agriculture in the CLMTV Countries and their Socio Economic Impacts, BRC Research Report, Bangkok Research Center, JETRO Bangkok/IDE-JETRO.

[31]Tho, L.C.B., Dung, L.C., Umetsu, C., 2021, One Must Do, Five Reductions, Technical Practice and the Economic Performance of Rice Smallholders in the Vietnamese Mekong Delta. Sustainable Production and Consumption 28 (2021) 1040–1049.

[32]Tivet, F., Boulakia, S., 2017, Climate Smart Rice Cropping systems in Vietnam. State of knowledge and prospects. Montpellier, France: CIRAD, 41 p.

[33]Toan, P.V., Sebesvari, Z., Blasing, M., Rosendahl, I., Renaud, F.G., 2013, Pesticide management and their residues in sediments and surface and drinking water in the Mekong Delta. Vietnam. Sci. Total Environ. 452–453, 28–39. doi: 10.1016/j.scitotenv.2013.02.026, Accessed on October 25th, 2021

[34]Toan, T.Q., 2014, Climate Change and Sea Level Rise in the Mekong Delta: Flood, Tidal Inundation, Salinity Intrusion, and Irrigation Adaptation Methods. In: Thao, N.D., Takagi, H., Esteban, M., (eds.), Coastal Disasters and Climate Change in Vietnam Engineering and Planning Perspectives.

[35]Tran, D.D., Chau, N.X.Q., Pham, D.T., Pham, G.T., Ho, V.H., Ngo, N.H.G., Le, T.T.H., 2020, Livelihood Vulnerability and Adaptation Capacity of Rice Farmers under Climate Change and Environmental Pressure on the Vietnam Mekong Delta Floodplains. Water 2020, 12, 3282; doi:10.3390/w12113282, Accessed on October 27th, 2021

[36]Tuan, L.A., Chinvanno, S., 2011, Climate Change in the Mekong River Delta and Key Concerns on Future.

[37]Vi, N.T.T., Liu, T.J., 2019, Improve the Competitiveness and Value of Rice Exports of the Mekong Delta Provinces. Agricultural Sciences, 10, 707-719. https://doi.org/10.4236/as.2019.106055, Accessed on October 27th, 2021

[38]Wadud, A., White, B., 2000, Farm household efficiency in Bangladesh: a comparison of stochastic frontier and DEA methods. Applied Economics. 32, 1665–1673.