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We have found that the eco rice farmers had higher input and output-oriented technical efficiency scores but insignificant compared to those with normal rice. The mean output-oriented technical efficiency of eco rice was 91.5%, which was 1% higher than that of traditional rice, 90.5%. Further, the mean input-oriented technical efficiency score of eco rice was 85% while only 83.5% for normal rice. The study suggests that the eco rice farmers need more efforts to expand output levels while the normal rice counterparts need to contract inputs level to improve productive efficiency and profits as well. The possible solution for the eco rice are not to use IR50404 variety. To improve the efficiency, the normal rice farmers need to cultivate three crops per year and to use OM6976 variety.

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1. INTRODUCTION

I ncreasing agricultural productivity, particularly in rice has been a long time and first prioritized objective in the Mekong Delta of Vietnam (VMD), where is widely known as “rice bowl” of Vietnam, contributing annually more than 50% of total rice production (GSO, 2013). Technically, rice productivity in Vietnam has been increased steadily as a result of the application of new technology; for instance, hybrid rice varieties with shorter duration, higher yield and tolerance with diseases and the use of chemical fertilizers and pesticides. Such increased use of agro-chemicals (Thi Ut & Kajis a, 2006) is the source of environmental pollution, causing biodiversity loss, water pollution and

public health impacts (Heong KL, 2009). Increasing demand on both quality (safer agricultural products in terms of lower use of agro-chemicals) and quantity (meeting population growth) has put more pressure on rice production –one of the staple food in Vietnam.

Owing to the importance of rice production in the VMD and its vulnerability to the outbreaks of brown-plant hoppers, the use of ecological engineering (abbreviated as eco hereafter), locally called as “*paddy field surrounded with flowers*” was first introduced in Tien Giang Province of the VMD since 2009 through the project which was technically coordinated by the international rice research institute (IRRI) and financially supported by Asian Development Bank (ADB). See the section of ecologically engineered rice production for more detailed information about ecological engineering.

The model was then expanded to other provinces of the VMD thanks to its achievement in terms of much lower use of pesticide cost despite of slightly higher cost for flower planting. However, after more than four years from the first introduction, there have been no studies which concern about the efficiency of the model in the VMD have been conducted. As such it is crucial to estimate the benefits of the model in terms of the potential to reduce inputs so-called “input-oriented technical efficiency” and to increase an output level so-called “output-oriented technical efficiency”.

So far, there have been two main approaches to estimate technical efficiency (TE) in the literature: data envelopment analysis (DEA) and stochastic frontier analysis (SFA). The results from these two methods differ slightly from each other. A reason for this difference is that SFA can separate noise effect apart from deterministic frontier while DEA can't. In addition, SFA is a parametric approach while DEA is non-parametric and based on mathematical programming. Depending on the purposes and the structure of data, we can choose one out of them or use both to estimate and compare the TE scores. In this study, we use SFA to estimate and compare the TE scores of eco rice farmers compared to those of traditional rice.

In 2004, Kompas estimated the TE scores of rice farmers in Vietnam by using panel data from 60 provinces and applying SFA. The study showed that the average TE was 78% for the Mekong Delta in 1999. Khai

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and Yabe (2011) also used SFA and the data from the Vietnam Household Living Standards Survey in 2006 to estimate such TE scores of 3,733 farmers. The study showed that the mean TE was 81.6%. However, neither of the two studies did consider about the stand-alone case of the VMD, particularly about eco rice.

Hence, it is essential to study the input-oriented and output-oriented TE of eco rice production as compared to traditional cultivation by using SFA and the factors affecting such efficiency scores.

The body of this paper is structured as follows. Section 2 describes the ecologically engineered rice production model in the VMD. Section 3 describes the analytical framework of using SFA to estimate the input and output-oriented TE and the data collection procedure. Following this, in section 4 we illustrate empirical results and discussions about TEs and the determinants affecting the efficiency for rice cultivation. Section 5 provides a summary and conclusions of the study.

II. ECOLOGICALLY ENGINEERED RICE PRODUCTION IN THE VMD

Mitsch and Jørgensen (1989) were probably the first to define ecological engineering. The term has been adjusted during the implementation. Basically, they characterized ecological engineering as it: a) contributes to the restoration of ecosystems that have been substantially disturbed by human activities such as environmental pollution from rice production (i.e. overuse of agro-chemicals), and b) promotes the development of new sustainable ecosystems that have both human and ecological values (biological control).

Following this methodology, after the serious outbreaks of brown-plant hoppers in some Asian countries like China, Thailand, Philippine and Vietnam, the IRRI launched the project so-called "Rice Plant Hopper Project", which applied the ecological engineering to biologically control pests, particularly brown-plant hoppers. The project was financially supported by the ADB. In the VMD, the ecological engineering in rice was introduced in Tien Giang Province as a demonstration plot since 2009. Under the project, participated farmers were basically provided flower seeds and required to plant that kinds of flowers on bunds around the periphery of their paddy fields. The model was then expanded to other provinces thanks to its expected efficiencies. An Giang Province, the study site, adopted this model in 2011 and assigned the Department of Plant Protection to deploy and monitor the project using such method. Currently, hundreds of farmers have been adopting the ecological engineering in their paddy fields (PPDAG, 2012).

According to PPDAG (2012), the implementation process of the ecological engineering is illustrated within six main steps as follows:

- *Step 1:* Flower variety selection: flower varieties having colors of white and/or yellow are more preferable; they have fast growth rate, much pollen and nectar; and it is notable that flowering vegetables are also acceptable and encouraged. Indispensable flower varieties are cosmos, daisy and sesame.
- *Step 2:* Cultivation time of flowers: the flowers are normally planted two weeks before sowing rice. However, depending on flowering or blooming time of certain varieties of flowers, farmers should choose appropriate time.
- *Step 3:* Planting methods of flowers: depending on certain varieties we should choose the proper methods: transplantation, cut branches or sowing. Minimum area required for the model is 10 hectares, which must have at least one large bund as a main source of flowers or home to natural enemies.
- *Step 4:* Caring of flowers: the flowers require to be watered frequently. This is the main constraint for the diffusion rate of the model. It should be noted to take advantages of secondary plants, which are able to grow after harvesting.
- *Step 5:* Rice cultivation and caring: Applying "3 decreases, 3 increases" and "1 right, 5 decreases". Regarding to "3 decreases, 3 increases" technology, farmers will focus mainly on how to **decrease** seed amount, fertilizers and pesticides and **increase** yield, quality and profit. Similar to the nature of "3 decreases, 3 increases" technology, "1 right, 5 decreases" method requires more attention on reducing losses and inefficient use of resource. The term "right" stands for recognized rice varieties and 5 decreases contain reduces of seed, fertilizers, pesticides, water and post-harvest losses.
- *Step 6:* Flower harvest and seed selection for next rice crop: Collect flower seeds for next crops to save costs and take advantages of secondary flowers, which are able to grow after harvesting and cutting.

These six steps of the ecological engineering can be graphically described in figure 1. As shown from figure 1 that the use of ecological engineering or flower planting aimed at increasing the populations in terms of abundance and diversity, of natural enemies or beneficial organisms. Such increased populations of these natural enemies contributes to suppress vertically and horizontally pests populations leading to lower use of agro-chemicals. Theoretically, the output levels of the paddy fields with the ecological engineering are expected to be identical with that of normal rice fields despite of lower use of agro-chemicals. Together with the application of ecological engineering, farmers were also required to adopt new technologies – "3 increases, 3 decreases" and "1 right, 5 decreases" in their paddy fields. These methods were aimed at reducing

production costs, including the reduction of agro-chemicals, which leads to higher profit and the protection of natural enemies as well. As consequences, paddy fields with ecological engineering have higher

biodiversity and abundance of natural enemies as well as lower application of agro-chemicals as compared with traditional rice fields.

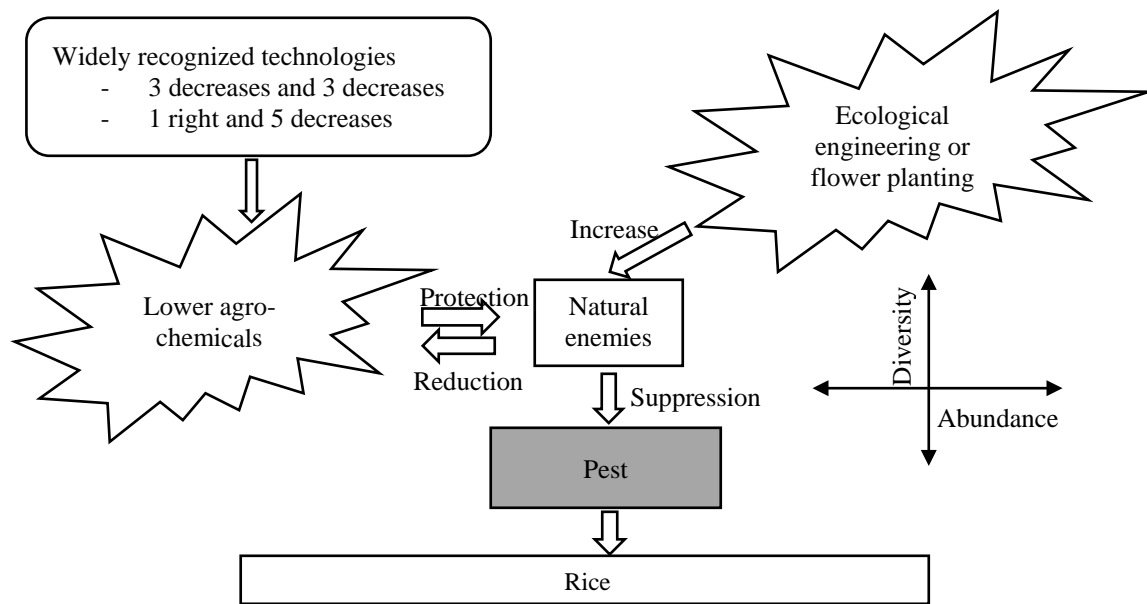


Figure 1 : The nature of the ecological engineering in An Giang Province

Source: the authors, 2015

III. METHODOLOGY

a) Measure of technical efficiency

In order to obtain the output-oriented TE, we assume a firm produces a vector of single output denoted as Y , with $Y \in R_+$ by using vector of inputs, which are denoted as X , with $X \in R_+$. In this study, we use Cobb-Douglas function form, which was commonly applied to estimate the stochastic production frontier in agricultural production (Battese, 1992; Bravo-Ureta & Pinheiro, 1993; Bravo- Ureta & Pinheiro, 1997; Coelli et al., 2005; Khai & Yabe, 2011). The stochastic production function of the i -th farmer in Cobb-Douglas form is given as follows

$$\ln Y_i = \beta_0 + \sum_{j=1}^j \beta_{ij} \ln X_{ij} + \varepsilon_i \quad i = 1, 2, \dots, N \quad (1)$$

where all farms are indexed with a subscript i ; j is numbers of explanatory variables; β_j are parameters to be estimated; ε_i is a composed error term with $\varepsilon_i = v_i - u_i$, where v_i is symmetric, independently and identically distributed as $(v_i \sim N[0, \sigma_v^2])$, represents the exogenous effects such as impacts of adverse weather, natural disasters and acts of God, measurement errors and other statistical noises; and u_i is half-normal and nonnegative random error ($u_i \geq 0$), distributed as

$u_i \sim N^+(0, \sigma_u^2)$, represents the technical inefficiency effect of the i -th farmer.

The output-oriented TE of the i -th farmer is obtained by multiplying e^{-v_i} on both sites of equation (1) and replacing the estimated parameters β with maximum likelihood estimates (MLE). This manipulation yields the measure of output-oriented TE as follows

$$OTE_i = e^{-u_i} = \frac{y_i}{f(X_{ij}, \beta_j^*) e^{v_i}} \quad (2)$$

According to Jondrow et al. (1982), u_i is predicted by the conditional expectation of u_i , given the value of random composed error variable ε_i . The expression of u_i is given by

$$E(u_i | \varepsilon_i) = \sigma^* \left[\frac{\phi(\varepsilon_i \lambda / \sigma)}{(1 - \Phi(\varepsilon_i \lambda / \sigma))} - \left(\frac{\varepsilon_i \lambda}{\sigma} \right) \right] \quad (3)$$

where $\sigma^* = (\sigma_u^2 \sigma_v^2 / \sigma^2)^{1/2}$; and $\phi(\cdot)$ and $\Phi(\cdot)$ represent the standard normal density and cumulative distribution functions.

As regards the input-oriented TE, Reinhard et al. (1999); and Reinhard et al. (2000) proposed setting $u_i=0$ and replacing all inputs in equation (1) with $\Phi_i Z_i$, where Φ_i is the i -th input-oriented TE score. This gives a new equation (4) as below

$$\ln Y_i = \beta_0 + \sum_1^j \beta_j \ln \Phi_i X_{ij} + v_i \quad (4)$$

They then set equation (4) and (1) equally to estimate the input-oriented TE scores. The manipulation yields

$$\sum_1^j \beta_j \ln \Phi_i X_{ij} - \sum_1^j \beta_j \ln X_{ij} + u_i = 0 \quad (5)$$

Some manipulation of equation (5) yields the expression of the input-oriented TE as follows

$$\ln ITE_i = \frac{-u_i}{\sum_1^j \beta_j} \Rightarrow ITE_i = e^{\left(\frac{-u_i}{\sum_1^j \beta_j}\right)} \quad (6)$$

It is notable that $\ln ITE_i = \ln ITE_i X_{ij} - \ln X_{ij} = \ln \left(\frac{ITE_i X_{ij}}{X_{ij}}\right)$.

The two measures of input and output-oriented TE are graphically illustrated in figure 2. The deterministic production function is described by the increasing, quasi-concave surface $OX_{2R}R_F X_{1R}$. Regarding to output-oriented TE, it is measured as the ratio of observed output level to maximum feasible output level that is reflected by $|OY_R|/|OY_F e^v|$ instead of $|OY_R|/|OY_F|$ because SFA approach can separate noise effects apart from deterministic frontier, where Y_R and $Y_F e^v$ are the observed and maximum feasible output level, respectively, of farm R. The plane ABCR is the identical output quantity of farm R. As such, input-oriented TE showing the ability to contract inputs, holding output level constant, is measured as radial reduction of all inputs by $|Y_R B|/|Y_R R|$. According to Färe and Lovell (1978), the two measures are identical under constant returns to scale.

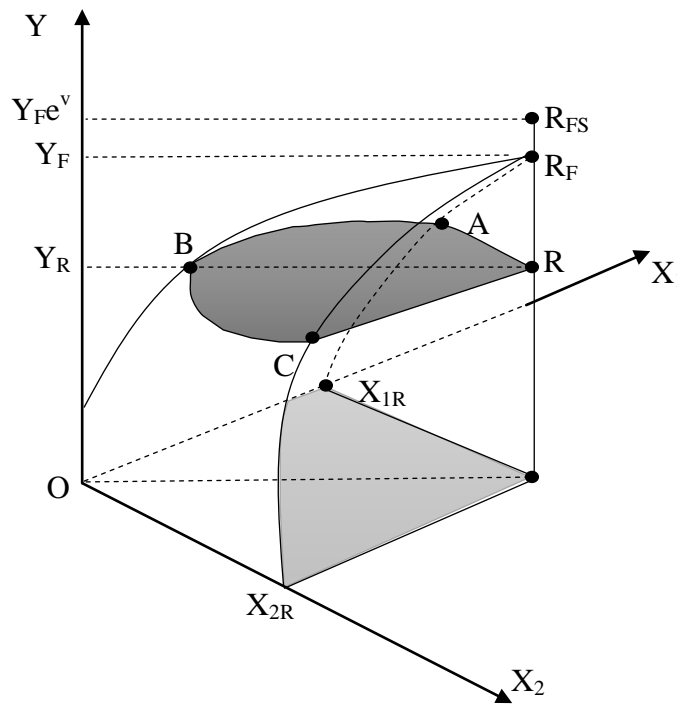


Figure 2 : Measures of output and input-oriented technical efficiency

Source: the authors, 2015

b) The factors affecting the efficiency

For policy implications and proper interventions, we use Tobit regression to identify the determinants of efficiency gaps, which was widely recognized as the second step of estimation in the literature (Bravo-Ureta & Pinheiro, 1993; Bravo-Ureta & Rieger, 1991; Bravo- Ureta & Pinheiro, 1997; Färe & Lovell, 1978; Khai & Yabe, 2011; Lee et al., 2009). The Tobit regression use efficiency scores as dependent variable having the scores censored at the maximum values. Independent

variables are farm-specific characteristics such as farm size, family size and seed rice varieties.

Stata software version 12 was used to estimate stochastic production frontier and measure TEs as well as the determinants affecting such efficiency scores.

IV. DATA COLLECTION AND ANALYSIS

We conducted face-to-face interviews with 199 farmers, in which 74 of those are eco rice farmers and

125 are normal rice counterparts. The survey was conducted in 2014 in An Giang Province of Vietnam, where was the second greatest rice producer in the VMD and adopted the ecological engineering since 2011(PPDAG, 2012). Based on the interviews with key informant panel of Provincial Center for Agricultural Extension An Giang, we selected 4 districts: Thoai Son, An Phu, Chau Doc and Chau Phu. These districts had

performed the most successful application about the model. The main contents of the survey included production technology, from which we can estimates TEs and farm-specific characteristics, which are used for Tobit regression to investigate the factors affecting the efficiency.

Table 1 provides brief summary about the data set used for estimating production function.

Table 1 : Brief summary of the data set used for estimating production function

Indicators	Unit	Eco rice		Normal rice		T-value
		Mean	St.dev.	Mean	St.dev.	
Yield	Kg	7097,03	686,18	7147,79	672,73	-0.51
Nitrogen	Kg	101,73	21,53	112,54	23,03	-3.27***
Potash and Phosphorus	Kg	119,98	26,42	116,12	19,89	1.17
Pesticide	T.VND	3570,76	1216,21	4539,16	1527,9	-4.65***
Energy	T.VND	1511,11	567,71	1576,32	534,14	-0.81
Seed quantity	Kg	100,18	51,53	153,61	80,69	-5.11***
Labor	Days	261,02	31,22	245,76	39,64	2.83***
Capital	T.VND	893,6	560,96	3771,91	2295,02	-10.59***
Other expenditures	T.VND	6898.43	3140.73	4708.86	1344.38	6.81***

Source: Own estimates, data available from the authors

Note: The numbers are the average values per hectare; *** indicates significant level of 1%

Results from Table 1 show that the total amount of labor invested for eco rice were significantly larger than that for normal rice at the 1% level of significance, which is due to the higher requirement of labor for planting and caring flowers. The pure amount of potash and phosphorus fertilizer, energy and other expenditures incurred for eco rice were in significantly different from that for normal rice. However, nitrogen, pesticide, seed quantity and capital of eco rice were significantly lower at the 1% level of significance.

As mentioned in section “ecological engineering”, eco rice was aimed at reducing pesticide use without compromising output level. In fact, the results from Table show that yield of eco rice was insignificantly lower than that of normal rice whereas pesticide use of eco rice farmers were significantly lower than those with normal rice at the 1% significant level. These results suggest that eco rice farmers achieved what they had expected from the adoption of ecological engineering.

V. RESULTS AND DISCUSSION

a) Technical efficiency

According to Bravo-Ureta and Pinheiro (1997); and Khai and Yabe (2011), before estimating the stochastic production function, ordinary least square regression (OLS) was used to identify the variables that significantly affect on the output. The estimates of the

OLS function represents the “average” production function while the MLE yields the stochastic production frontier. The results of both OLS and MLE models were presented in Appendix A. Although the variable capital is one of main explanatory factors (Battese, 1992; Battese & Coelli, 1988; Bravo-Ureta & Pinheiro, 1997; Coelli et al., 2005; Khai & Yabe, 2011; Meeusen & Van den Broeck, 1977; Reinhard et al., 1999), it was excluded from the model in our study because of its insignificant correlation.

It is clearly shown in Appendix A that in case of OLS estimation, seed quantity was significant at the 10% level, labor and other expenditures were significant at the 5% level while the others were significant at the 1% level. In the case of MLE estimation, all parameter estimates were significant at the 1% level. The results from Breusch-Pagan test and Variance Inflation Factor (VIF) showed that neither multicollinearity nor heteroskedasticity was found in the model. According to Coelli et al. (2005), we could use either LR test or z-test to check the presence of technical inefficiency. Based on z-test, the z-value was 369.44 (i.e., 4.8766/0.0132), which exceeds the z-critical value of 3.09 at the 0.1% level of significance, suggesting that we reject the null hypothesis that there is no technical inefficiency.

In the Cobb-Douglas function, the coefficients show the proportional change in output when all inputs are changed. The sum of elasticities with respect to all

inputs represents the production technology or returns to scale. According to Bravo-Ureta and Pinheiro (1997), the stochastic production function is the product of neutral upward shift of the average function, suggesting that the sum of elasticities of the both models (the OLS and MLE) are quite similar.

The sum of elasticities with respect to all inputs was approximately 0.52 in case of OLS and 0.54 in case of MLE (see Appendix A), which indicates that returns to

scale are decreasing for rice farmers in the study sites. The computed F-statistic is 41.54, which exceeds the critical F value of 2.74 at the 1% level of significance, the null hypothesis of constant returns to scale therefore was rejected.

Now we turn to estimate the input and output-oriented TEs. Table 2 summarizes the TEs scores for both eco rice and normal rice.

Table 2 : Input and output-oriented TE scores of eco and normal rice

TE levels	Eco rice				Normal rice			
	Output		Input		Output		Input	
	Count	%	Count	%	Count	%	Count	%
≥90	46	62.2	24	32.4	80	64.0	47	37.6
80-90	28	37.8	26	35.1	31	24.8	37	29.6
70-80	0	0.0	23	31.1	12	9.6	23	18.4
≤70	0	0.0	1	1.4	2	1.6	18	14.4
Mean TE	91.5		85.0		90.5		83.5	
St.dev.	4.7		8.0		7.0		11.5	
Min	80.6		67.1		69.3		50.8	
Max	99.1		98.4		98.9		97.9	

Source: Own estimates, data available on request from the authors

As regards the output-orientation, the mean TE score of eco rice was 91.5%, which was about 1% higher than that of traditional rice, 90.5%. Further, the TE of normal rice had greater variation than that of eco rice with the former ranging from 69.3% to 98.9% while the latter falling in a range from 80.6% to 99.1%. These results suggest that eco rice farmers with minimum scores have the potential to increase the output level by 19%, while 30% for normal rice farmers, conditional on observed levels of inputs. As compared to those with the highest efficiency, the average eco rice farmers and normal rice farmers could realize to expand their output levels by approximately 7.7% (i.e., $1 - [91.5/99.1]$) and 8.5% (i.e., $1 - [90.5/98.9]$), respectively.

With regard to the input-orientation, as expected under the context of decreasing returns to scale, the input-oriented TE scores were smaller than the output-oriented TE scores. In fact, in the both cases of eco and normal rice, the input-oriented TE scores in the average was about 6.5% and 7.5%, respectively, smaller than the output-oriented TE scores. The mean TE score of eco rice (85%) was about 1.5% higher compared to those of normal rice (83.5%). Similarly, the input-oriented TE scores of normal rice had greater variation than that of eco rice, implying that eco rice farmers made use of inputs more efficiently, providing the observed level of output is constant.

Although eco rice farmers have joined the projects on the use of ecological engineering and received many technical training courses, which aimed at reducing production cost or inputs, it seems to be that the farmers focused much more on the production

that the farmers focused much more on the production or output level than inputs contraction. A supported evidence for the statement is that 100% of the farmers had the output-oriented TE ranged above 80% while only about 67% in case of the input-oriented TE. Further, more than 30% of the farmers having the input-oriented TE scores distributed below 70%. However, as compared to those of traditional rice cultivation, the efficiency scores and distribution of eco rice was higher for all, suggesting positive and good signals of the use of ecological engineering and efforts of local extension workers.

Results from t-test, which was used to compare the significant difference in mean efficiency scores between eco rice and normal rice, show that t-values for input-oriented TE and output-oriented TE were 1.08 and 1.21, respectively. Although these results indicate that they were insignificantly different from each other at the 10% by using one-tail test, the differences in the accumulative distribution maybe reflects the potential benefits of eco rice. The detailed information about the differences in distribution of TEs scores between eco rice and normal rice is illustrated in figure 3.

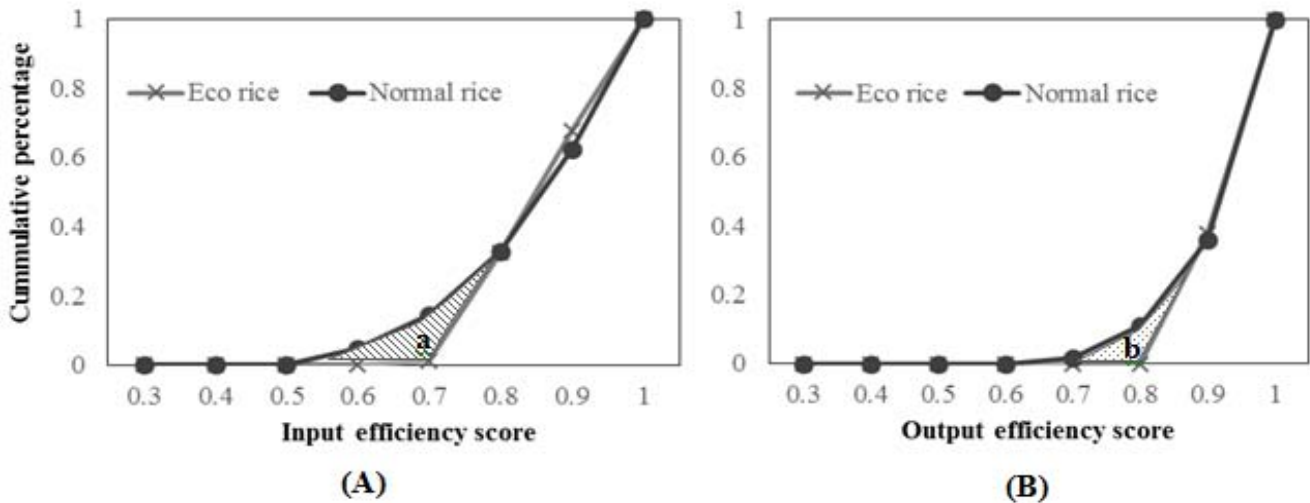


Figure 3 : Cumulative distribution of efficiency scores by groups of farmers

Source: the authors, 2015

As shown in figure 3 that the areas a and b indicate partially the potential losses of normal rice as compared to eco rice in both cases of input saving and output expansion, respectively. In fact, in case of input orientation, about 20% of normal rice farmers had scores distributed below 70% while 0% for eco rice counterparts, which reflects the positive effects of eco rice. According to figure 3 (A), as compared to a starting point of input-oriented TE of eco rice at 70%, those of normal rice with efficiency scores at 50%, 60% could

realize to reduce about 29% and 14%, respectively, of their current use of inputs.

Similarly, in case of output-oriented TE, normal rice farmers with scores at 70% could recognize to contract about 12.5% compared with the starting point of eco rice. Moreover, in terms of efficiency, the potential losses of normal rice compared to eco rice were bigger in case of input-oriented TE than that of output-oriented TE ($a > b$).

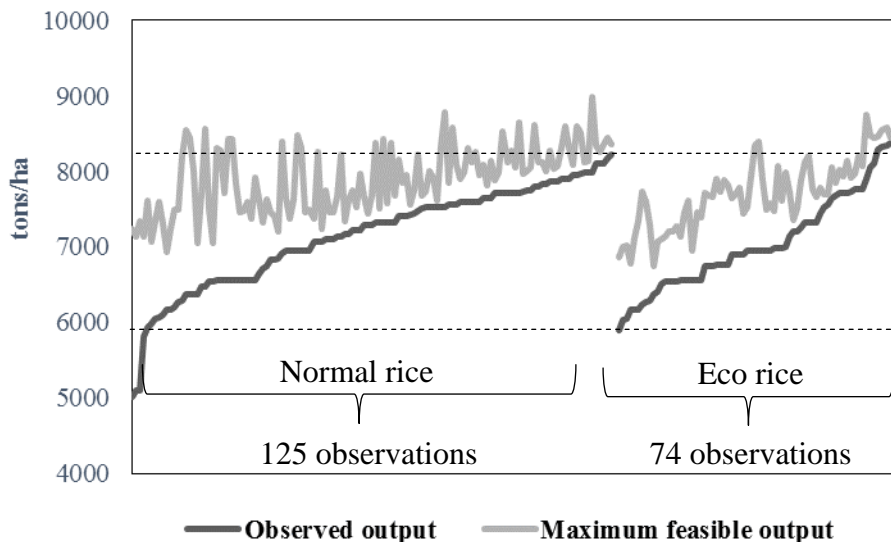


Figure 4 : Observed output and maximum feasible output

Source: the authors, 2015

For drawing better policy implications, the study also provide the general picture of observed output and stochastic frontier, which is illustrated in figure 4.

According to figure 4 and table 1, although the yields of eco rice and normal rice were not significantly

different from each another, the distribution of observed output levels of eco rice was a bit higher as compared to that of normal rice; for instance, there were no eco rice farmers had output levels below 6 tons/ha. As regards stochastic production frontier, the farmers with

normal rice had higher variation, particularly for those with observed output levels below 7.5 tons/ha, compared to those with eco rice. Under the context of decreasing returns to scale, a possible explanation is that those farmers extremely overused inputs levels. This result suggests that normal rice farmers need to pay more attention on the reduction of inputs to improve productive efficiency and profit as well.

On the contrary, the eco rice farmers need more efforts to consider the ways to improve output levels because the maximum possible output was approximately 9 tons/ha (figure 4). In the current situation, output expansion is one of the best solutions to attract more farmers to adopt the ecological engineering. However, output expansion based on inputs justification is not a profitable undertaking due to decreasing returns to scale. It is therefore essential to investigate the factors affecting the efficiency gaps.

b) *The factors affecting the efficiency*

So far, we estimated two kinds of technical efficiency: output-oriented and input-oriented TE for both eco rice and normal rice. Although the study suggest that the eco rice farmers should focus on output expansion while the normal rice farmers need

more efforts to contract inputs, for broader options and different viewpoints of intervention, we will consider all kinds of efficiency in this section. In Tobit regression, all of them (kinds of efficiency) were considered as dependent variables to investigate separately the determinants of efficiency gaps.

The associated independent variables were farm-specific characteristics, including farm size (*farsize*), family size (*famsize*), numbers of crops per year (*crop*), sources of rice seed (*seed*), three main rice varieties (*IR50404*, *OM6976* and *Jasmine*), pumping methods (*pump*) and eco rice (*eco*). These variables are those commonly incorporated in this step of estimation (Ahmad & Bravo-Ureta, 1996; Bozoğlu & Ceyhan, 2007; Bravo-Ureta & Evenson, 1994; Bravo-Ureta & Rieger, 1991; Bravo-Ureta & Pinheiro, 1997; Khai & Yabe, 2011). The detailed explanation of the variables are described in Table 3. The variables *farsize*, *famsize*, *sesource*, *OM6976*, *Jasmine* and *Eco* were expected to have significantly positive effects on the four types of efficiency scores while the variables *crop*, *IR50404* and *pump* have negative signs. The results of estimates with Tobit regression are presented in Table 3.

Table 3 : Tobit regression coefficients

Variables	Description	Eco rice		Normal rice	
		OTE	ITE	OTE	ITE
<i>Farsize</i>	Paddy area (ha)	0.0027**	0.0069**	-0.0006	-0.0010
<i>Famsize</i>	Number of members	0.0054	0.01290	0.0117***	0.0262***
<i>Crop</i>	1 = three crops/year 0 = two crops/year	-0.0120	-0.0286	0.0685***	0.1632***
<i>Sesource</i>	1 = verified source, 0 = otherwise	-0.0275**	-0.06992**	0.0012	0.0003
<i>IR50404</i>	1 = IR50404, 0 = otherwise	0.0197	0.0466	-0.0374**	-0.0800**
<i>OM6976</i>	1 = OM6976, 0 = otherwise	-0.0233	-0.0580	-0.0184	-0.0466
<i>Jasmine</i>	1 = Jasmine, 0 = otherwise	0.0411*	0.1017*	-0.0280	-0.0690
<i>Pump</i>	1 = self-pumping, 0 = co-operative	0.0441***	0.1098**	-0.0121	-0.0261
Constant		0.8742***	0.6728***	0.8129***	0.5386***
Sigma		0.0401	0.1010	0.0576	0.1328
Log-likelihood		129.9063	62.1061	176.9969	73.2951

Note: ***, ** and * represent the significant levels of 0.01, 0.05 and 0.1, respectively

OTE = output-oriented TE and ITE = input-oriented TE

Source: Own estimates, data available on request from the authors

It is clearly shown in Table 4 that as a whole the variables that had positively significant impacts on the efficiency scores of eco rice was negatively significant in case of normal rice and vice versa. In the scope of this study, we had no explanation for this trend.

As regards eco rice farmers, the two variables *Crop* and *IR50404* had significant and negative impacts on the two types of efficiency (input and output-oriented TEs) at the significant level of 5%. The negative coefficients of *Crop* on both output and input-oriented TEs suggest that those who cultivated three rice crops per year had lower TEs scores as compared to those who cultivated only two crops annually. At first, the possible explanations are due to the overexploitation of soil fertile. However, this variable had positive and significant impacts on both TEs in case of normal rice. We could not make a plausible explanation for this adverseness.

Regarding to *IR50404*, the marginal effects of this variable in case of input-oriented TE and output-oriented TE were -5.1% and -8.7%, respectively, which indicates that the eco rice farmers who used IR50404 rice variety had lower TEs scores than those who used other varieties such as Jasmine and OM6976. In fact, the government has recommended not to use this rice variety massively because of its low quality.

Regarding to normal rice farmers, the variables *Crop* and *OM6976* had positive and significant connections with both input and output-orientated TEs at the 5% level of significance. The positive coefficient of *Crop* indicates that farmers cultivating three crops per year had higher TEs scores as compared to those producing annually two crops. As regards rice varieties, farmers who adopted OM6976 variety had higher TEs scores than those who used other ones.

VI. CONCLUSIONS

The study applied SFA to estimate and compare technical efficiency of 74 eco rice farmers to 125 normal rice counterparts in An Giang Province of Vietnam. We also investigated the determinants of efficiency gaps for all types of efficiency by using Tobit function.

We have found that returns to scale are decreasing. The farmers with eco rice had higher efficiency scores but insignificant as compared to those with normal rice. The mean output-oriented TE score of eco rice was 91.5%, which was 1% higher than that of traditional rice, 90.5%. The mean input-oriented TE score was also higher for eco rice (85%) than for normal rice (83.5%). Moreover, in terms of efficiency, the potential losses of normal rice compared to eco rice were bigger in case of input-oriented TE than that of output-oriented TE. As regards stochastic production frontier, the farmers with normal rice had greater variation, particularly for those with observed output levels below 7.5 tons/ha, compared to those with eco rice. Under the context of decreasing returns to scale, a possible explanation is that those farmers extremely overused inputs levels. The study also found that the maximum possible output was approximately 9 tons/ha.

The study suggests that the normal rice farmers need to pay more attention on the reduction of inputs to improve productive efficiency and profit as well while the eco rice farmers need more efforts to expand output levels. To improve the output-oriented TE for those of eco rice, results from Tobit regression show that the farmers should not use IR50404 variety and produce only two crops per year. To improve input-oriented TE for the normal rice farmers, besides new technology development, the study suggests that they need to cultivate three crops per year and to use OM6976 rice variety.

a) Competing interests

The authors declare that they have no competing interests.

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Appendix A : Coefficients of production functions with OLS and MLE

Predictor	OLS		MLE	
	Coefficient	Std. error	Coefficient	Std. error
Nitrogen quantity	0.0899***	0.0305	0.1000***	0.0277
Potash and phosphorus	0.0937***	0.0304	0.0996***	0.0252
Pesticide cost	0.0639***	0.0176	0.0535***	0.0157
Energy cost	0.0622***	0.0167	0.0663***	0.0129
Seed expenditure	0.0133*	0.0078	0.0186***	0.0058
Labor	0.1343**	0.0633	0.1491***	0.0506
Other expenditures	0.0608**	0.0264	0.0534***	0.0204
Constant	5.6608***	0.4533	5.6901***	0.3601

Function coef.	0.5181	Function coef.	0.5405	
F-test model	13.9200	λ	4.8766	0.0132
F-test CRS	41.5400	σ^2	0.0160	
R ²	0.3378	Log Likelihood	238.1771	

Note: ***, ** and * indicate statistically significant levels of 1%, 5% and 10%, respectively.

Source: Own estimates, data available from the authors.

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