Technical efficiency of rice producing households in the Mekong Delta of Vietnam

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ABSTRACT

Technical Efficiency (TE) is defined as an estimation of the ability of a household to produce the maximum output with the given inputs. It is usually estimated by using the data envelopment analysis (DEA) and stochastic frontier analysis (SFA). Data collected from 261 rice farming households in the Mekong Delta were used in the empirical analysis. Results show that the average TE among the surveyed households is above 76% in both the Constant (CRS) and the Variable Returns to Scale (VRS). The average scale efficiency score for these rice producing households is nearly one. The determinants of the quantity of rice or yields and of the TE for the households are significantly related with some variables such as the plot size, seed, and hired labor cost. However, technical inefficiency significantly depends on the farmers' farming experience and adoption of advanced farming practices.

INTRODUCTION

Rice is grown as a main crop in most Asian countries, and is a major source of livelihood of their rural population. Asia is home to near 4 billion people who consume over 90 percent of the world's rice production. The "Green Revolution" has created an opportunity for Asia to become largely self-sufficient in rice. This resulted from adopting advanced farming techniques promoted during the Green Revolution era. In 2002, more than 50% of the world's population was consuming rice as a staple food, being a main source of calories in the diet.

Rice production in Vietnam was low until the 1960s-1970s, because the cultivated areas did not yet apply advanced farming techniques. However, by the mid-1980s, production had reached an annual growth rate of 5%. During the period from 1980 to 2000, the increase in productivity and in cultivated areas had contributed 3.5% and 1.5% to this growth, respectively (Tran 2002). Since 1989, Vietnam has become one of the world's three leading rice exporters. Export volume in 2009 was 6 million tons with a value of USD 2.6 billion (Kim, 2010).

The efficiency of rice production has been of longstanding interest to the economists and policymakers in Asia because of the strong relationship between rice production and food security in the region (Richard et al. 2007). To the Mekong Delta (MD) of Vietnam, the development of rice production has been important not only for helping ensure the country's food security but also its supply for export.

It is evident that measuring the productive efficiency of an industry is important to both the economic theorist and the economic policy maker (Farrell 1957). Of the models used to estimate the production efficiency at the household level, the two most popular are the data envelopment analysis (DEA) and the stochastic frontier analysis (SFA). These two have been widely applied by some authors in their work, among them Banker et al. (1978), Chen (2002), Tran (2002), Hien (2003), Linh (2007), and Nhut (2007).

The central objective of this research is to estimate the technical efficiency (TE) of rice production of households in the MD region and identify the factors that determine TE. Analyzing the rice production efficiency in the Mekong Delta is very important in planning socio-economic policy for the following reasons: first, to provide quantitative efficient measures of this product in the MD region; second, to determine optimal allocation of inputs towards a higher productive efficiency; and finally, to evaluate potentials of inefficient factors in the rice production process.

REVIEW OF THE LITERATURE ON RICE PRODUCTION EFFICIENCY

In the agricultural sector, adoption of advanced technique (or technology) may take various forms such as using a new variety, changing the farming process, altering the resource inputs, combining different farming practices, and so on (Ellis 1993). The goal of adopting advanced techniques is to gain higher economic efficiency, which is measured in better productivity. It brings many positive social effects as well, e.g., enhancing the working conditions, improving livelihoods, or conserving the environment.

Since the 1950s, a wide range of experimental studies have been conducted about the contribution of advanced farming techniques and activities of the agricultural extension, including the growth of the agricultural sector. Some of the more recent studies on the country's rice production were conducted by Tran (2002), Hien (2003), and Linh (2007). All of them indicate that the application of improved practices in rice farming has led not only to increases in yield, but has also contributed to reducing poverty in the rural areas.

According to estimates of the IPM[1] club of rice farmers in Soc Trang province, their production cost decreased by 22.85% and their profit grew by 33%, compared with the traditional[2] rice farming (Soc Trang Agricultural Extension Center, 2004).

Various researches have been conducted on the impact of advanced techniques on the rice production efficiency in developing countries. Some of those were done by Bordey (2004), Chengappa et al. (2003), and Khuda (2005). Most results prove that the advanced rice production techniques demonstrate higher efficiency than the traditional farming.

Some reviews of the rice production efficiency for the case of Vietnam are found in the empirical works by Tran (2002), Hien (2003), and Linh (2007). Agricultural researchers have paid a lot of

[1] Integrated Pest Management was funded and conducted by the DANIDA project (Denmark) since 1992.
[2] This implies rice farming with no application of technological advances.

attention to this area of study for the last two decades, especially with regard to the Mekong Delta. Such research has partly informed the formulation of socio-economic development policies in the region. The Delta or MD is best known for its rice farming and is often referred to as Vietnam's rice basket. This region has been the country's largest rice producer and exporter since 1989.

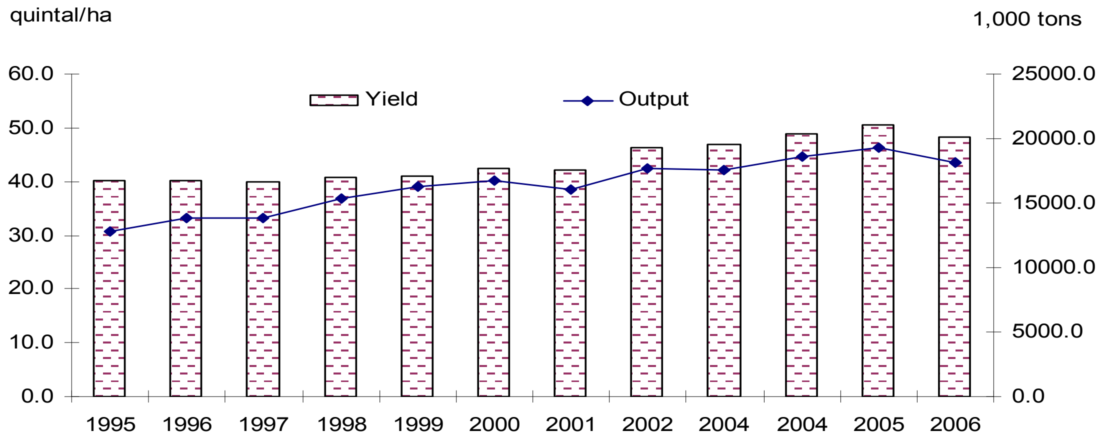

Figure 1: Rice production in the Mekong Delta, 1995 - 2006

Source: GSO, 2006

Note: 1 quintal = 100 kg

It is worth noting that despite the existing literature and studies on rice technical efficiency, scant attention has been given to specific research on advanced rice farms in this region where the following techniques are popular: use of new varieties, integrated pest management or IPM, fish-rice farming, vegetable-rice farming, seeding by rows, and the 3 gains - 3 reductions technique[3]. In this research, the author used DEA and SFA tools to estimate technical efficiency and its determinants for rice households in the MD region, guided by the analytical framework below.

[3] 3 gains (yield, quality, income) - 3 reductions (fertilizers, chemicals/pesticides, costs)

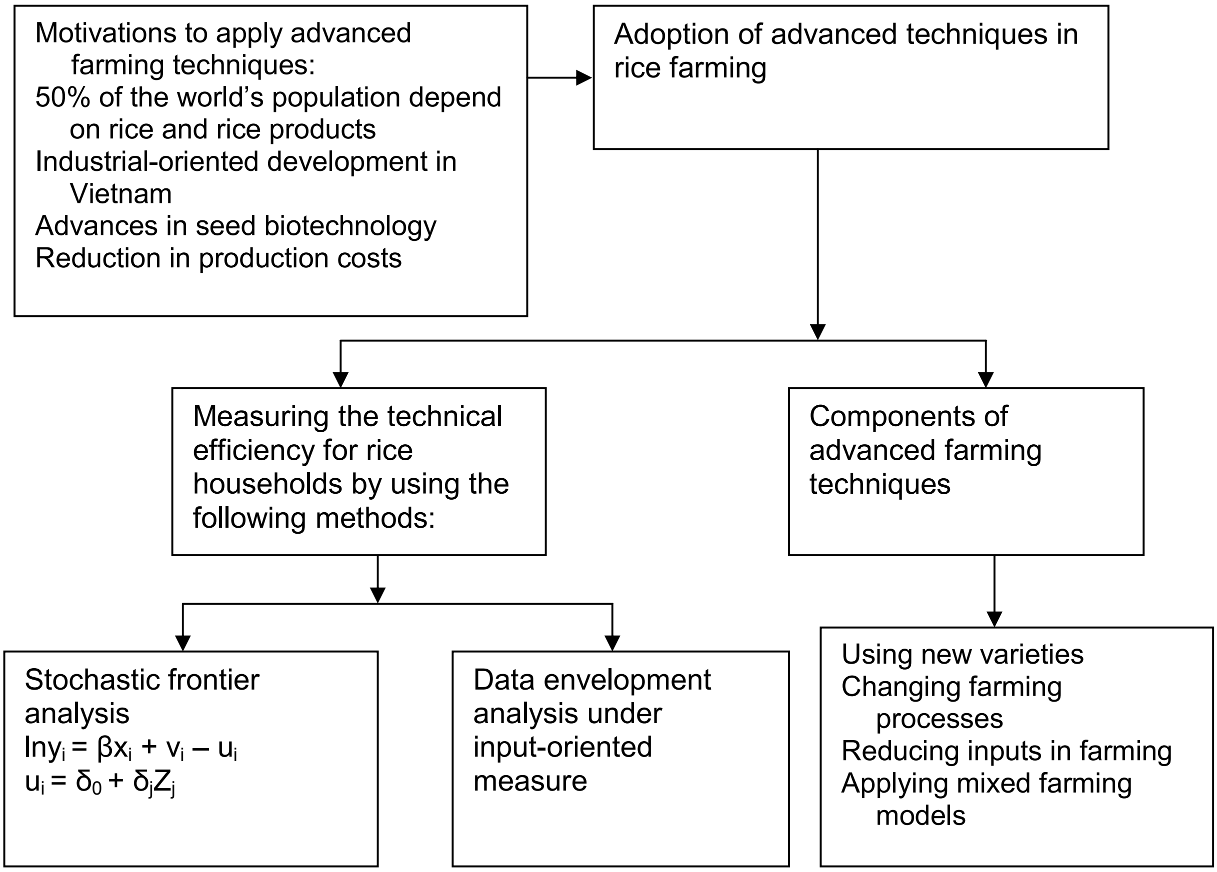

Figure 2: Analytical framework of the technical efficiency of rice farming

The main reasons for adopting advanced rice farming in Viet Nam and particularly in the MD region are: (1) increase in the demand for rice in the world market, mainly in Asian and Middle Eastern countries; (2) conversion of agricultural land for industrial development; and (3) development of crop biotechnology (especially in rice). These reasons induce farmers to apply advances in rice production aimed not only to increase productivity and quality of rice, but also to reduce production costs and save or conserve natural resources (e.g., water, soil, etc.).

As mentioned earlier, technological advances in rice production can take different forms, for example: use of varieties that are high yielding, of short duration, and highly pest resistant; integrated pest management (IPM); better water management; seeding in rows; mixed farming; and the like. Due to differences in crops, soils, geography, and water sources in each cultivated location, rice farmers in those areas have to select the most suitable farming method or model towards an optimal productive efficiency.

In addition, researchers often use the DEA and SFA techniques to estimate efficiency and identify the related measures such as technical, scale and allocative efficiencies as well. Scores of technical and scale efficiencies will give us a picture of rice production of households and indicate how to allocate inputs in an optimal way. On the other hand, results of SFA will provide scores of TE and will also indicate determinants of technical efficiency and inefficiency. In sum, these expected results are likely to be seen as useful references for policy makers in the MD region.

DATA DESCRIPTION AND METHODOLOGY

Selection of the Study Sites

Based on the research objectives, the study sites had to be representative of the typical rice production area in the region. In this regard, Can Tho and Soc Trang provinces were chosen. In addition, most of the rice research agencies are located in these provinces; these agencies provide technical support to farmers such as the Mekong Delta Rice Research Institute and Can Tho University at the Can Tho site; and the Soc Trang Agricultural Extension Center and Crop Seeding Center at the Soc Trang site.

Figure 3: Map of the Mekong Delta

Source: http://cantho.cool.ne.jp/ameder/map/blank6.gif

Data Source and Sampling

The collected data typify the spring-winter rice crop[4] in 2006. Purposive sampling was used to choose the 261 respondents from the two provinces, shown in Table 1. The respondents were selected to ensure a representation of the variety of different conditions in the farm households – namely the plot

[4] The spring-winter crop, one of three in a year, gives the highest yield and is considered as the main rice crop. Its cycle begins in November and ends in February of the next year.

sizes, years of farming experience, rice yields, and the selected input variables. Apart from selecting the farm households by location, the data set was also constructed to include 209 households that applied advanced farming practices and 52 others that did not. This stratification was done to enable the researcher to compare and evaluate the productive efficiency among the various models of rice farming.

Table 1: Number and percentage of households in the study sites.

Province	Study sites	Sample	Percent
Can Tho	Thoi Lai	65	24.90
	Thoi Long	96	36.78
Soc Trang	Phu Tam	60	19.54
	Ho Dac Kien	40	15.33
Total		261	100.00

Source: Survey data, 06/2006

Some of the advanced rice farming models in the Can Tho sites included the use of new varieties, IPM, seeding by rows, the 3 gains-3 reductions model, fish-rice and vegetable-rice combinations; whereas in Soc Trang, IPM, new varieties, and the 3 gains-3 reductions were commonly practiced.

Methods for Analysis

The data envelopment analysis (DEA) and the stochastic frontier analysis (SFA) are two alternative methods for estimating the frontiers functions and for measuring the efficiency of production. The DEA involves the use of linear programming, whereas the SFA involves the use of econometric methods (Coelli et al. 1998). Both methods were used in the study, using the DEA for estimating the technical and scale efficiency of the rice farming, and the SFA for measuring the parameters of the productive frontier and for testing the hypotheses as well. Using the DEA and SFA are appropriate for this kind of study and the nature of the study sites, where data are heavily influenced by the measurement error and the effects of natural conditions like weather, diseases, flooding, and the like (Coelli et al. 1998).

The Data Envelopment Analysis

The DEA is a mathematical programming technique used to identify efficient frontiers for the peer decision making units (DMUs). In addition, it is a collection of non-parametric methods to measure the production efficiency of farms. This tool was originated by Farrell (1957), but the term "data envelopment analysis" became more popular following the work of Charnes et al. (1978). There is a large number of work concerning this methodology as applied by some authors (Charnes et al. 1978; Banker et al. 1978; and specially Coelli et al. 1998); the last one has written a popular computer program – the DEAP version 2.1 – used to construct the DEA frontier for the calculation of the TEs and the CEs.

In this paper, the input-orientated measures were used to estimate the TE and the SE, because the output and the input-orientated measures are equivalent measures of the TE (Coelli et al. 1998). In addition, the output-orientated measures are considered as a case of production that involves two outputs and a single input. Therefore, the application in this paper of the input-orientated measures is an appropriate analysis in which the rice quantity is referred to as the output, and plot size, seed, fertilizers, pesticides, and soil preparation and fuel costs are identified as the selected inputs.

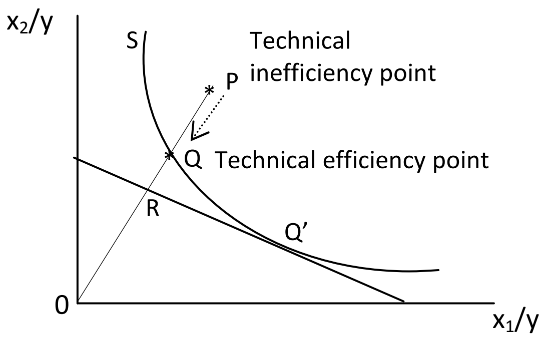

Figure 4: TE measure

Source: Cited from Collie et al. 1998

The input orientation involves the households which use a number of inputs (x_i) to produce a certain rice output (y) under the assumption of the CRS. The unit of the isoquant of fully efficient households which is represented by the S curve in Figure 4 allows us to measure the TE. If any household uses a quantity of inputs (defined by the point P) to produce a unit of output, the technical inefficiency of that household could be represented by the distance of QP, which is the amount of inputs that can be proportionally reduced without a change in output.

The TE of each household will be estimated by the following ratio:

$$TE_i = OQ/OP \quad (1)$$

The resulting TE will take a value between zero and one, and hence it provides an indicator of the degree of the technical inefficiency of the household. If the value is one, it indicates that the household is fully technically efficient. Point Q in Fig 4 shows that it lies on the efficient isoquant.

To calculate the TE, we must define some notations first, and assume that there is a set of selected input variables (called K) and output (namely M) for each of the households (N). For the i^{th} household, these are represented by the column vectors x_i and y_j respectively. The K*N input matrix (X), and the M*N output matrix (Y), present the data for all N households. For the j^{th} household out of *n* households, the input-based TE under the CRS is obtained by solving the following problem:

$$Min_{\theta,\lambda}\ \theta, \quad (2)$$

subject to $-y_i + Y\lambda \geq 0,$

$\theta x_i - X\lambda \geq 0,$

$\lambda \geq 0,$

where the value of θ obtained will be the TE score for the i^{th} household. It will satisfy $\theta \leq 1$, with a value of 1 indicating a point on the frontier and hence, that household gains full TE; y_i is the output of i^{th} farm, λ is (N x 1) a vector of intensity variables. The linear programming problem must be solved N times, once for each household in the sample and a value of θ is then obtained for each one (Coelli et al. 1998).

In case of variable returns to scale, the CRS model can be modified to account for the VRS by adding the convexity constraint: $N1'\lambda = 1$ to the CRS model.

$$Min_{\theta,\lambda}\ \theta, \quad (3)$$

subject to $-y_i + Y\lambda \geq 0,$

$\theta x_i - X\lambda \geq 0,$

$N1'\lambda = 1$,

$\lambda \geq 0$,

where N1 is an Nx1 vector of ones. Thus, the technical efficient score under the VRS is always equal to or greater than the technical efficient score under the CRS.

Therefore, both the CRS and the VRS methods are used in this paper to estimate the TE, because the CRS assumption is only appropriate when all households are operating at an optimal scale. However not all households may operate optimally due to imperfect competition, financial constraints, and other factors (Collie et al. 1998).

Calculation of the Scale Efficiency (SE)

The SE is estimated by the ratio between the CRS and the VRS technical efficiency scores. It means that if there is a difference in the CRS and the VRS scores for a particular household, then this indicates that the household has scale inefficiency (Collie et al. 1998). These concepts can be expressed in ratio efficiency measures as:

$$TE_{CRS} = AP_c / AP \quad (4)$$

$$TE_{VRS} = AP_v / AP \quad (5)$$

$$SE = AP_c / AP_v \quad (6)$$

All of these measures are bounded by zero and one. If a certain household operates at a point R in Fig 5, then this household reaches a full optimal scale.

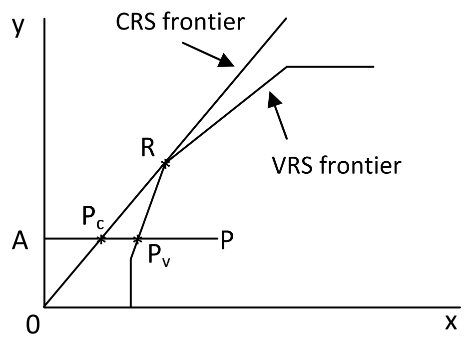

Figure 5: The production frontier curve

Source: Cited from Collie et al. 1998.

In addition, the Returns to Scale (the RTS) score for each of the households is measured to point out how a certain household operates according to the relationship between the proportion of inputs and the output. In economics, the RTS is expressed either as constant, increasing, or decreasing. The RTS is determined by calculating the total elasticity of the production, ε (Collie et al. 1998) shown in the formula below:

$$\varepsilon = \sum_{i=1}^{n} E_i \qquad (7)$$

$$E_i = \frac{\partial y}{\partial x_i} * \frac{x_i}{y} \qquad (8)$$

where E_i is the partial elasticity of the production for each input, and the value of ε is related to the RTS in Table 2.

Table 2: Relation of the Returns to Scale (the RTS) and the total elasticity of the production

Returns to scale (RTS)	Total elasticity of the production (ε)
Constant	=1
Increasing	>1
Decreasing	<1

Source: Cited from Collie et al. 1998.

A constant RTS means that the output increases by the same proportional change of inputs (CRTS). If the output increases by less than the proportional change of inputs, it is called the Decreasing Returns to Scale (DRTS). In contrast, if the output increases by more than the proportional change of inputs, it is called the Increasing Returns to Scale (IRTS).

The Stochastic Frontier Analysis (the SFA)

The SFA is another method of economic modeling. It had its starting point in the stochastic production frontier models that were simultaneously introduced by Aigner et al. (1977) and Meeusen and Broeck (1977). They independently proposed a stochastic frontier production function with an additional random error. The stochastic frontier model is currently formed as follows:

$$\ln(y_i) = \beta x_i + v_i - u_i, \qquad i = 1,2,\ldots, n \qquad (9)$$

where $\ln(y_i)$ is the logarithm of the output for the i^{th} household;

x_i is a (K+1) row vector, whose first element equals 1 and the remaining elements are the logarithms of the K-input quantities used by the i^{th} household;

β is a (K+1) column vector of unknown parameters to be estimated;

u_i is a non-negative random variable associated with technical inefficiency in production of household;

v_i is random error accounting for measurement error and other random factors such as the effects of weather, diseases, etc.

Testing of hypotheses is an indispensable process as the stochastic frontier is applied to measure the TE, with the null hypothesis that there is no technical inefficiency effects in the model and with the alternative hypothesis, conversely. According to Collie et al. (1998), the one-sided generalized likelihood ratio (LR) test should be performed when maximum likelihood estimation is involved because this test has the correct size.

H_0: ($\gamma = 0$): there is no technical inefficient effect, u_i,

H_1: ($\gamma > 0$): there is technical inefficient effect

The test statistic is calculated as:

$$LR = -2\{\ln[L(H_0) - \ln[L(H_1)]\}$$

where $L(H_0)$ and $L(H_1)$ are the values of the likelihood function under the null and alternative hypotheses. The critical value for this LR test of size α is equal to the value of $\chi^2(2\alpha)$. Therefore, the model specification of the stochastic frontier function is defined as:

$$\ln(y_i) = \beta x_i + v_i - u_i, \qquad i = 1,2,\ldots, n \qquad (10)$$

where

y_i = Quantity of rice (kg)

x_1 = Plot size (1,000m^2)

x_2 = Seed cost (VND[5]/cropping)

x_3 = Fertilizer cost (VND/cropping)

x_4 = Pesticide cost (VND/cropping)

x_5 = Other costs (e.g. soil preparation, seeding, fuel) (VND/cropping)

x_6 = Hired labor cost (VND/cropping)

x_7 = Family labor (person)

Simultaneously, the non-negative random variable, u_i, for estimating the technical inefficiency of household is expressed as follows:

$$|ui| = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 Z3 + \delta_4 Z_4 \quad (11)$$

where

Z_1 = Schooling of household head (level)

Z_2 = Farming experience (years)

Z_3 = Advanced farming practices (1: applied; 0: not applied)

The stochastic frontier model permits one to estimate parameters, standard errors and to test the hypotheses using the maximum likelihood method. The parameter vectors β and δ are estimated together with the variance parameters $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2 / \sigma^2 = \dfrac{\sigma_u^2}{\sigma_v^2 + \sigma_u^2}$. All parameters in the model are estimated under the Frontier 4.1 program written by Collie et al. (1998).

Using SFA to estimate technical efficiency has the following advantages in comparison with using DEA (Son 2010): First, SFA has possibility to considerably restrict the effect of statistical noise and extreme observations on the estimation results. Second, the results are considerably less sensitive to small data update or estimated model specification correction. However, SFA also has some weaknesses in that the functional form of the frontier and the distribution form of the random variable presenting technical inefficiency of households are initially selected, so it is possible to face misspecification as well as an increase in the subjectivity of estimation results.

[5] Vietnamese Dong; 1 USD = 19,100 VND (exchange rate as of August 2010)

Currently, DEA and SFA are widely used in estimating technical efficiency at the household level in both the agricultural and industrial sectors (Hien 2003; Den et al. 2007). Most of these authors often examine determinants of TE towards endogenous inputs in the production process. Those factors are mainly material inputs and human capital.

EMPIRICAL FINDINGS

Data Envelopment Analysis (DEA) Measure

In this sub-section, we attempt to analyze the data with a two-stage process. First, we measure the TE and SE scores of the 261 households included in the study using DEA. In the second stage, the determinants of the TE scores are identified by using the TE scores as a dependent variable.

The technical efficiency scale scores of the rice farms estimated through the DEA 2.1 program are expressed in Table 3. The average technical and scale efficiency scores are above 0.76 and 0.96. In general, all the advanced rice farming models in the study sites have not reached an optimal level in terms of both TE and SE. These estimates of farming models are relatively close to Binh's study results (2007) of the agricultural economic farming in Can Tho; and likewise, with the findings of Hien (2003) and Linh (2007) regarding the efficiency of rice farming households in Vietnam.

Table 3: The technical and scale efficiency scores of various rice farming models.

Items	DEA		
	CRS	VRS	SE
Average score	0.761	0.788	0.966
Number (and %) of efficient households	28 (10.7%)	40 (15.3%)	32 (12.2%)
Of which,			
Advanced farming models	0.777	0.803	0.968
Traditional farming	0.699	0.730	0.958
Efficiency scores of advanced farming			
New variety	0.772	0.795	0.971
IPM	0.791	0.818	0.968
Row seeding	0.761	0.799	0.954
3 reductions – 3 gains	0.788	0.816	0.966
Fish – rice farming	0.773	0.802	0.966
Vegetable – rice farming	0.834	0.876	0.953

Source: Calculated by the author using the DEA 2.1 program

VRS = TE scores under variable returns to scale
CRS = TE scores under constant returns to scale
SE = scale efficiency score

Out of the 261 rice farming households that were observed, 32 operated at CRTS; this means that the output these 32 households increased by the same proportional increase in the inputs used. Twenty (20) households operated at DRTS, i.e., the increase in output is proportionately lower than the increase in inputs. Meanwhile, the remaining 209 households operated at IRTS – indicating that they obtained an output that increased by more than the same proportional change in inputs. The DEA results show that of the 261 households, 28 (10.7%) were fully efficient under the CRS and 40 (15.3%) under the VRS. It is found that the mixed vegetable-rice farming obtained the highest TE because of reduced fertilizer and pesticide use.

Now returning to the second stage of this sub-section, a regression model was used to identify the relationship between the TE score and some of the predictor variables that include number of years of schooling, farming experience, adoption (1: applied advanced farming; 0: otherwise) and location (1: Can Tho; 0: Soc Trang). The TE score obtained from the DEA above is now considered as a dependent variable which is explained by some predictor variables, including the characteristics of the rice producing household (Den et al. 2007).

The coefficients estimated from the linear regression model are shown in Table 4. Note that more than 11.2% of the variance in the TE scores can be explained by a change of the predictor variables at 0.05 level of significance. Most of these predictor variables have a significant relationship with the TE score, except for the schooling of household heads. In addition, there is no collinearity among predictor variables, because the Variance Inflation Factors (VIF) of all predictor variables are less than two (see Annex 2).

Table 4: Determinants of the Technical Efficiency for the rice households.

Model	Coefficients	Std. Error	Sig.
Constant	0.780	0.034	0.000
Years of schooling	0.003	0.011	0.821
Years of farming experience	-0.002	0.001	0.007
Adoption of advanced farming	0.067	0.019	0.001
Location	-0.041	0.016	0.012
R^2	0.112		
F	8,109		
Sig.	0.000		

Source: Calculated by the author.

The results suggest that if the households adopt the advanced rice farming practices, they will obtain a higher technical efficiency. This is consistent with the economic theory, because a household will take advantage of the advanced technologies (e.g., use of new high yielding varieties) as a substitute for labor force to increase its TE.

The result indicated that duration of farming experience has a negative effect on the TE. This may indicate that the farmers are more inclined to follow the agricultural technicians' guidelines regarding advanced farming technologies rather than replying on their traditional practices.

In addition, there is a difference in the TE between the two study areas, e.g., the farm households in Soc Trang have obtained a higher TE than those in Can Tho. Specifically, the yield of rice in Soc Trang is almost 10% higher than in Can Tho (see Annex 3). According to interviews with agricultural experts and agricultural extension officials, the higher rice yield in Soc Trang is mainly due to better irrigation networks and adoption of good production practices with guidance from local agricultural officials.

Stochastic Frontier Analysis (SFA) measure

Maximum likelihood estimates the parameters of the stochastic frontier and the inefficiency model is presented in Table 5. The significance of $\gamma = 0.000$ and $\sigma^2 = 0.0144$ (approximately zero) at 1%. This means that the technical inefficiency effects mainly originate from the measurement term (σ_v^2), not from σ_u^2. In addition, the likelihood ratio (LR) test of the one-sided generalized error calculated by Frontier is 21.7 which exceeds the critical value (α =5%) at 7.779 from the Table χ^2 probability. Hence, the null hypothesis (that there is no technical inefficiency effect in the rice production) is rejected. This indicates that the coefficients of the frontier production function are significantly different from the average production function estimated with the Maximum Likelihood Estimation or MLE model (Collie et al. 1998). Although there is collinearity of some of the independent variables (e.g. plot size, seed, fertilizers), the indicators of tolerance and VIF in Annex 4 found that there is not enough evidence to drop them from the model, because a certain variable will be dropped from the model only if its VIF index is more than 10.

The estimates of the stochastic function reported in Table 5 exhibited the signs of parameters that are more consistent with some empirical findings by authors like Kompas (2002), Hien (2003), Tijani (2006), and Linh (2007). The independent variables such as the plot size and other costs (e.g., soil preparation) are significantly positive for the quantity of rice. This means that an increase in the plot size for rice farming is associated with a higher yield. Similarly, an additional cost for preparing the soil before seeding significantly contributes to increase in rice yields.

As commonly known, most advanced rice farming practices are intended to reduce (inorganic) fertilizer use, minimize production costs, and lessen agriculture's negative environmental effects. For example, by practicing row seeding, a farmer can reduce the amount of seed needed by 80-120 kg per hectare and the labor required for seeding work; and by following IPM, a farmer would spend less on fertilizers and pesticides, but amount (or costs) of the inputs saved are usually underestimated.

Table 5: Estimation of the stochastic frontier function for the rice farming households.

Model	Parameter	Coefficient	Standard error	t-ratio
Constant	β_0	7.597***	0.353	21.542
Log plot size	β_1	1.088***	0.033	33.097
Log seed	β_2	-0.053**	0.024	-2.229
Log fertilizer	β_3	-0.017	0.023	-0.749
Log pesticide	β_4	0.015	0.016	0.958
Log other costs	β_5	0.021*	0.013	1.662
Log hired labor	β_6	-0.037***	0.012	-3.127
Log family labor	β_7	-0.014	0.023	-0.618
Technical inefficiency				
Years of schooling	δ_1	0.012	0.012	1.050
Years of farming experience	δ_2	0.002**	0.001	2.402
Adoption of advanced farming	δ_3	0.077***	0.022	3.580
Sigma-squared	σ^2	0.014***	0.001	10.887
Gamma	γ	0.000	0.072	0.000
Log likelihood estimation = 182.67; R^2 = 0.973				
LR test of the one-sided error = 21.70				

Source: Calculated by the author using Frontier 4.1 program.
*= significant at 10%; **= significant at 5%; ***= significant at 1%

For the technical inefficiency function, the estimated coefficients are significant at various levels. Specifically, the negative value of parameters in the technical inefficiency function indicates the positive influence on the yield or quantity of rice for the households. Among these variables, the farmer's experience has statistically significant effect on the technical inefficiency for the rice-growing households.

As was earlier discussed in the DEA result, the farmer's experience does not appear to contribute to increasing the quantity of rice for the households. However, the calculation also finds that the profit of those who adopted advanced farming models is higher than those who practiced traditional farming. This result is likely the most important factor that induces farmers to adopt the advanced rice farming models.

In short, the findings discussed above satisfied the objectives of this study. More specifically, the study was able to accomplish the following: provided an appropriate tool for measuring the TE of rice producing farmers in the Mekong Delta; determined the important factors influencing the farmers' TE; and identified the potential determinants of inefficiency of the farmers in the study sites.

CONCLUSION

Through the use of DEA and SFA tools to estimate the technical efficiency of 261 rice-producing households in the two provinces of Soc Trang and Can Tho, several conclusions are drawn.

First, the DEA results showed the technical and scale efficiency scores of all observed households. Of the six rice farming models, mixed rice farming (i.e., vegetable-rice and fish-rice) obtained higher TEs than the monocrop rice farming, mainly due to the reduction in the use of fertilizers and pesticides. Moreover, farmers often adopt advanced rice farming instead of the traditional practice, with the guidance and encouragement of local agricultural officials. As a result, average score of scale efficiency for advanced rice faming models is higher. Another finding is that 209 out of 261 households obtained an increased return to scale while only 20 in the survey showed decreased RTS.

Second, the SFA results allowed us to identify the determinants of the technical efficiency and inefficiency of the rice-farming households. Of those explanatory variables in the model, plot size, costs of seed, and hired labor have significant positive effects on technical efficiency of the households.

Finally, these results of estimation are important to deepen understanding of the beneficial impacts of adopting advanced rice farming to rice producing households They may help local policy makers in crafting policies that are conducive to increasing technical efficiency in rice production in the Mekong Delta. For economists and academics, this research has shown that DEA and SFA are appropriate tools for estimating the TE of agriculture in developing countries. On a more practical level, the results can also be used as guide in advising farmers on appropriate strategies for increasing their productive efficiency and addressing areas of inefficiency.

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APPENDICES

Appendix 1. Summary of the DEA result.

EFFICIENCY SUMMARY:

household	crste	vrste	scale	
1	0.773	0.846	0.914	irs
2	0.785	1.000	0.785	irs
3	0.948	0.959	0.988	irs
4	0.903	0.927	0.973	irs
5	0.793	1.000	0.793	irs
6	0.614	0.644	0.952	irs
7	0.796	0.860	0.926	irs
8	0.922	0.942	0.978	irs
9	1.000	1.000	1.000	-
10	0.721	0.756	0.954	irs
…. …	…	…	…	…. …
259	0.610	0.639	0.994	irs
260	0.816	0.830	0.984	irs
261	0.663	0.667	0.994	irs
mean	0.761	0.788	0.966	

Appendix 2. Testing collinearity of DEA model.

Testing Collinearity[a]

Model		Correlations			Collinearity Statistics	
		Zero-order	Partial	Part	Tolerance	VIF
1	Schooling	.013	.014	.013	.867	1.153
	Experience	-.180	-.169	-.161	.920	1.088
	Model (1: Advanced; 0: Traditional)	.244	.213	.205	.961	1.041
	Location (1:CT; 0:ST)	-.197	-.156	-.149	.903	1.107

a. Dependent Variable: Technical Efficiency Score

Note: CT = Can Tho city; ST = Soc Trang province.

Appendix 3. Differences in rice yield between Can Tho and Soc Trang.

Descriptives

Yield

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Soc Trang	100	831.8000	104.48682	10.44868	811.0675	852.5325	500.00	1100.00
Can Tho	161	714.4534	80.47018	6.34194	701.9287	726.9781	550.00	1040.00
Total	261	759.4138	106.81276	6.61154	746.3948	772.4328	500.00	1100.00

ANOVA

Yield

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	849427.4	1	849427.410	103.926	.000
Within Groups	2116904	259	8173.374		
Total	2966331	260			

Robust Tests of Equality of Means

Yield	Statistic(a)	df1	df2	Sig.
Brown-Forsythe	92.173	1	171.018	.000

a Asymptotically F distributed.

Appendix 4. Testing collinearity of SFA model.

Testing Collinearity [a]

Model		Correlations			Collinearity Statistics	
		Zero-order	Partial	Part	Tolerance	VIF
1	LogPlot size	.983	.901	.342	.109	9.191
	LogSeed	.859	-.141	-.023	.189	5.292
	LogFertilizer	.879	-.047	-.008	.145	6.914
	LogPesticide	.831	.061	.010	.244	4.102
	LogOthers	.719	.106	.018	.463	2.158
	LogHirelabor	.437	-.197	-.033	.633	1.579
	LogFamily labor	.054	-.039	-.006	.924	1.083
	Schooling	-.077	-.067	-.011	.827	1.210
	Experience	.140	-.147	-.025	.853	1.173
	Farming	-.111	-.228	-.039	.834	1.200

a. Dependent Variable: LogOutput