Technical Efficiency of Rice-Producing Households in the Mekong Delta of Vietnam

Huynh Truong Huy
Antwerpen University, Belgium
Can Tho University, Vietnam
E-mail: huynhtruonghuy@gmail.com

ABSTRACT

Technical Efficiency (TE) is 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 percent 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 associated 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 the rural population. Asia is home to nearly 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 by promoting adoption of advanced farming techniques. In 2002, more than 50 percent 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 cultivated areas had not applied advanced farming techniques. However, by the mid-1980s, production had reached an annual growth rate of 5 percent. From 1980 to 2000, the increase in productivity and in cultivated areas contributed 3.5 percent and 1.5 percent to this growth, respectively (Tran 2002). Since 1989, Vietnam has become one of the world's three leading rice exporters having an export volume of 6 million tons with a value of USD 2.6 billion in 2009 (Kim 2010).

The efficiency of rice production has been an interest to economists and policymakers in Asia because of the strong relationship between rice production and food security in the region (Richard et al. 2007). In the Mekong Delta (MD) of Vietnam, development of rice production has been important to ensure the country's food security and its export supply.

Measuring the productive efficiency of an industry is important to both the economic theorist and the economic policymaker (Farrell 1957). The two most popular models used to estimate the production efficiency at the household level 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 main objectives of this research are to estimate the technical efficiency (TE) of rice production among 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 socioeconomic policy for the following reasons: first is to provide quantitative efficient measures of this product in the MD region; second is to determine the 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 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, experimental studies on the contribution of advanced farming techniques, activities of agricultural extension, and the growth of the agricultural sector have been done. More recent studies on the country's rice production were conducted by Tran (2002), Hien (2003), and Linh (2007), all of them indicate that improved practices in rice farming have led to yield increase and poverty reduction 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 percent and their profit grew by 33 percent, compared with traditional[2] rice farming (Soc Trang Agricultural Extension Center 2004).

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

Some reviews of the rice production efficiency in Vietnam are found in the empirical works by Tran (2002), Hien (2003), and Linh (2007). Agricultural researchers have paid a lot of attention to this area of study during the last two decades, especially with regard to the Mekong Delta. Such research has been part of the formulation of socioeconomic development policies in the region. The Delta or MD is known for its rice farming and is often referred to as Vietnam's rice basket. This region has been

[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.

the country's largest rice producer and exporter since 1989.

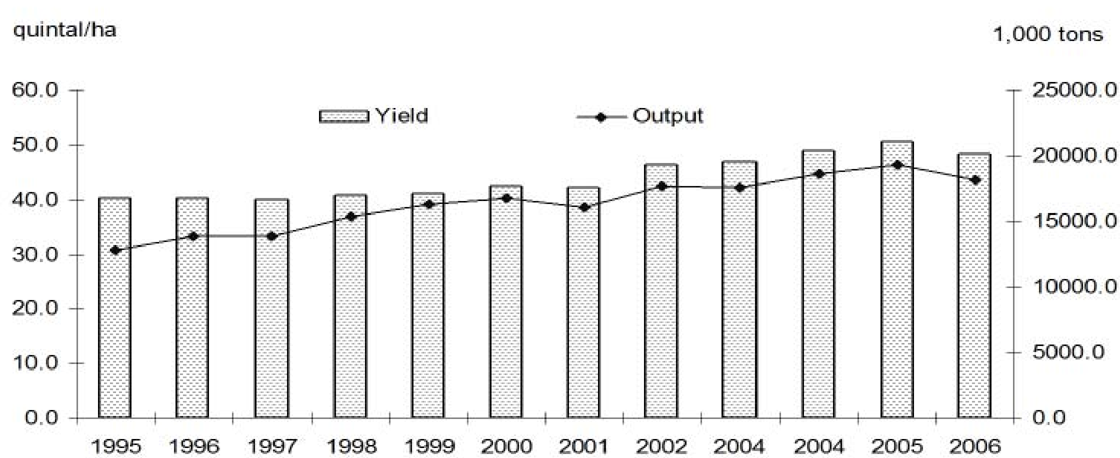
It is worth noting that despite the existing literature and studies on rice technical efficiency, scant attention has been given to specific research on advanced rice farms in this region, where the following techniques are popular: use of new varieties, integrated pest management or IPM, fish-rice farming, vegetable-rice farming, seeding by rows, and the 3 reductions - 3 gains technique[3]. In this research, the author used the tools, DEA and SFA, to estimate technical efficiency and its determinants for rice-farming households in the MD region, guided by the analytical framework in Figure 2.

The main reasons for adopting advanced rice farming in Vietnam 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 to increase productivity and quality of rice, 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. Scores of

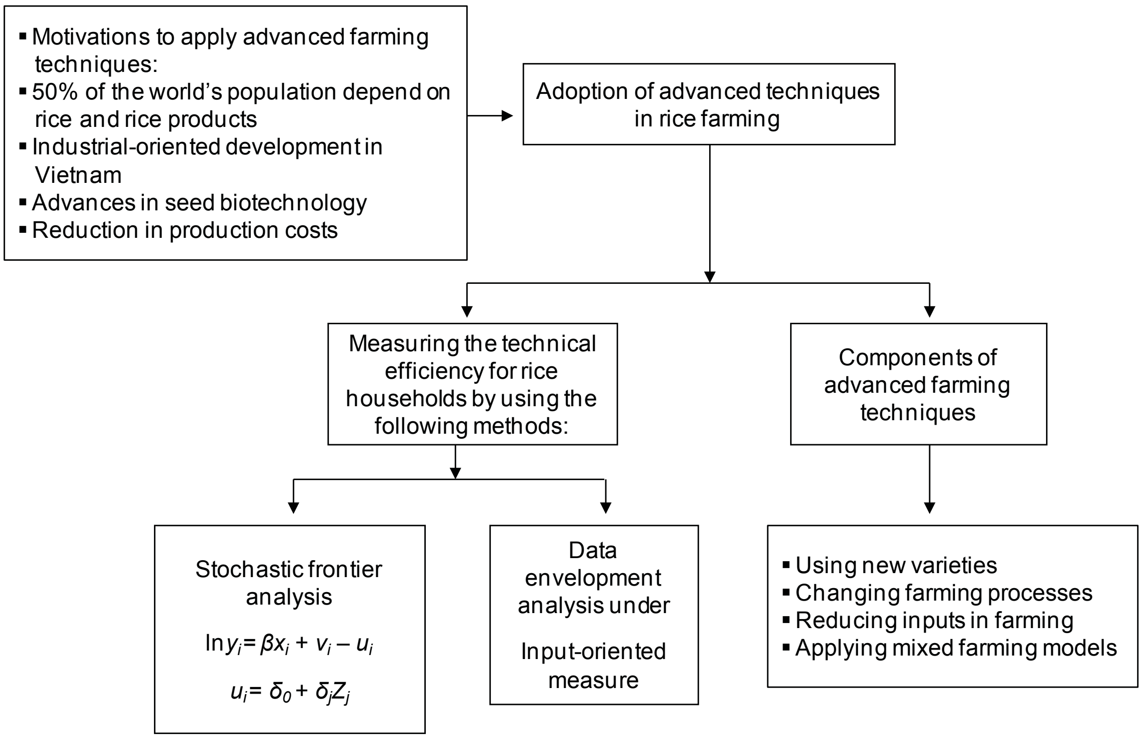
Figure 1. Rice production in the Mekong Delta, 1995 – 2006



1 quintal = 100 kg
Source: GSO

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

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



technical and scale efficiencies illustrate rice production among households and indicate how to allocate inputs in an optimal way. On the other hand, results of SFA provide scores of TE and also indicate determinants of technical efficiency and inefficiency. In sum, these expected results are likely to be seen as useful references for policymakers in the MD region.

DATA DESCRIPTION AND METHODOLOGY

Selection of the Study Sites

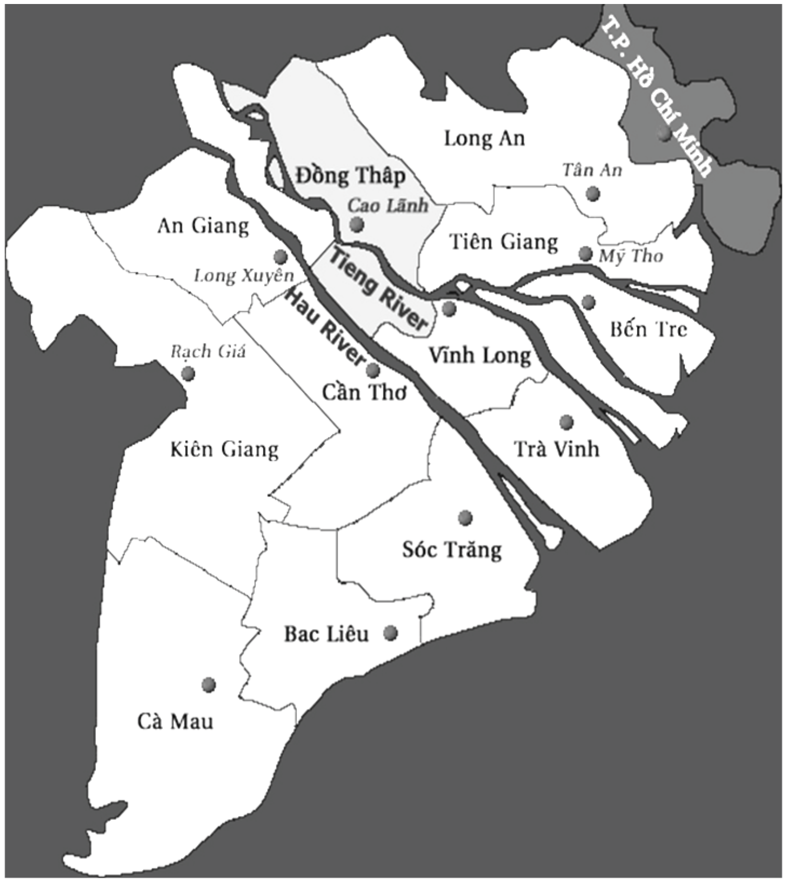
Based on the research objectives, the study sites should represent the typical rice production area in the region. In this regard, Can Tho and Soc Trang provinces were chosen. In addition, most of the rice research agencies, such as the Mekong Delta Rice Research Institute and Can Tho University at the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

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

[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.

Figure 3. Map of the Mekong Delta



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

two provinces (Table 1). The respondents were selected to ensure a representation of the variety of different conditions in the farm households, namely: plot sizes, years of farming experience, rice yields, and the selected input variables. Apart from selecting farm households by location, the dataset was also constructed to include 209 households that applied advanced farming practices and 52 others that did not. This stratification was done to compare and evaluate the productive efficiency of the various models of rice farming.

Some of the advanced rice-farming models in the Can Tho sites included the use of new varieties, IPM, seeding by rows, the 3 reductions - 3 gains 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 frontier functions and the efficiency of production. The DEA involves the use of linear programming, whereas the SFA involves the

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, June 2006

use of econometric methods (Coelli et al. 1998). Both methods were used in the study: DEA for estimating the technical and scale efficiency of the rice farming, and SFA for measuring the parameters of the productive frontier and for testing the hypotheses. Using DEA and SFA are appropriate for this study and the nature of the study sites, where data are heavily influenced by measurement error and the effects of natural conditions like weather, diseases, flooding, and the like (Coelli et al. 1998).

Data Envelopment Analysis

The DEA is a mathematical programming technique used to identify efficient frontiers for the peer decision-making units (DMUs). It is also a collection of non-parametric methods to measure production efficiency of farms. This tool originated from 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 in this methodology as applied by some authors (Charnes et al. 1978; Banker et al. 1978; and Coelli et al. 1998). Coelli et al. has written a popular computer program, the DEAP version 2.1, used to construct the DEA frontier to calculate TEs and the CEs.

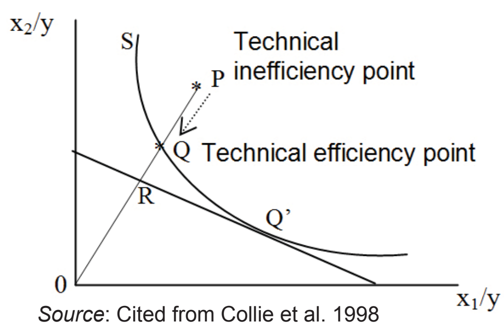
In this paper, the input-oriented measures were used to estimate the TE and the SE, because the output and the input-oriented measures are equivalent measures of the TE (Coelli et al. 1998). In addition, output-oriented measures are considered a case of production that involves two outputs and a single input. Therefore, the application input-oriented measures is an appropriate analysis in which 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.

Input orientation involves 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, represented by the S curve in Figure 4, measures *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:

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

Figure 4. TE measure



Source: Cited from Collie et al. 1998

The resulting *TE* will take a value between 0 and 1. Hence, it provides an indicator of the degree of the technical inefficiency of the household. If the value is 1, it indicates that the household is technically efficient. Point Q in Figure 4 shows that it lies on the efficient isoquant.

To calculate *TE*, we must define some notations, and assume that there is a set of selected input variables (called *K*) and output (namely *M*) for each household (*N*). The i^{th} household is represented by the column vectors x_i and y_j respectively. The *K*N* input matrix (X), and the *M*N* output matrix (Y), represent 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:

$$\text{Min}_{\theta,\lambda}\ \theta, \qquad (2)$$

$$\text{subject to} \quad -y_i + Y\lambda \geq 0, \quad \theta x_i - X\lambda \geq 0, \quad \lambda \geq 0,$$

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.

$$\text{Min}_{\theta,\lambda}\ \theta, \qquad (3)$$

$$\text{subject to} \quad -y_i + Y\lambda \geq 0, \quad \theta x_i - X\lambda \geq 0, \quad N1'\lambda = 1, \quad \lambda \geq 0,$$

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

Therefore, both the CRS and the VRS methods are used to estimate 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 Scale Efficiency

Scale efficiency (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:

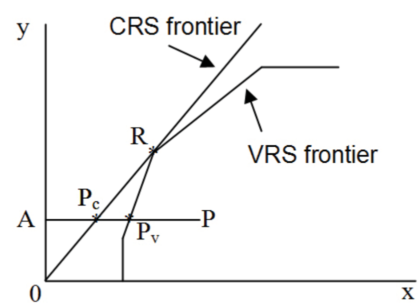
$$TE_{CRS} = AP_c/AP \qquad (4)$$

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

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

All of these measures are bounded by zero and one. If a certain household operates at a point R in Figure 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 (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:

$$E_i = (\partial y / \partial x_i)(x_i / y) \quad (7)$$

$$E_i = (\partial y / \partial x_i)(x_i / y) \quad (8)$$

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.

A constant RTS means that output increases by the same proportional change of inputs (CRTS). If 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).

Stochastic Frontier Analysis

Stochastic frontier analysis (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:

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

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

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.

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 TE. The null hypothesis is: there is no technical inefficiency effects in the model; while the alternative hypothesis is, conversely, there is technical inefficiency effects in the model. According to Collie et al. (1998), the one-sided generalized likelihood ratio (LR) test should be performed when the 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:

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

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:

$$|u_i| = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 Z_3 + \delta_4 \delta_4 \qquad (11)$$

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 estimates parameters, standard errors and test hypotheses using the maximum likelihood method. The parameter vectors β and δ are estimated together with the variance parameters

$$\sigma^2 = \sigma_v^2 + \sigma_u^2 \quad \text{and}$$
$$\gamma = \sigma_u^2 / \sigma^2 = \sigma_u^2 / (\sigma_v^2 + \sigma_u^2)$$

[5] 1 USD = 17,749.18 VND (June 2009)

All parameters in the model were estimated using the Frontier 4.1 program written by Collie et al. (1998).

In estimating technical efficiency, SFA has the following advantages over DEA (Son 2010). First, SFA can restrict the effect of statistical noise and extreme observations on the estimation results. Second, the results are less sensitive to small data update or estimated model specification correction. However, the SFA has some weaknesses. The functional form of the frontier, and the distribution form of the random variable that presents the technical inefficiency of households are initially selected. Therefore, it can face misspecification and increase occurrence of subjectivity in the estimation results.

The DEA and SFA are used in estimating technical efficiency at the household level in agricultural and industrial sectors (Hien 2003; Den et al. 2007). Most 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, the data are analyzed using a two-stage process. First, we measure the TE and SE scores of the 261 households using DEA. In the second stage, the determinants of the TE scores are identified by using TE scores as the dependent variable.

The TE scale scores of rice farms estimated through the DEA 2.1 program are shown in Table 3. The average technical and scale efficiency scores are above 0.76 and 0.96. The advanced rice-farming models in the study sites have not reached an optimal level in their TE and SE. These estimates of farming models are close to the results of the study of Binh (2007) on the agricultural economic farming in Can Tho, and Hien (2003) and Linh (2007) on the efficiency of rice-farming households in Vietnam.

Out of the 261 rice-farming households observed, 32 operated at CRTS, wherein their output increased proportionately with the increase in inputs. Twenty (20) households operated at DRTS, which implies that the increase in output is proportionately lower than the increase in inputs. The remaining 209 households operated at IRTS, indicating that their output increased by more than the same proportional change in inputs. The DEA results show that out of the 261 households, 28 (10.7%) were fully efficient under the CRS and 40 (15.3%) under the VRS. Mixed vegetable-rice farming obtained the highest TE because of reduced fertilizer and pesticide use.

On the second stage, a regression model was used to identify the relationship between the TE score and some of the predictor variables, such as, number of years in school, farming experience, adoption (1 - applied advanced farming, 0 - otherwise) and location (1 - Can Tho, 0 - Soc Trang). The TE score, obtained from the DEA, is the dependent variable 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. More than 11.2 percent 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 are associated with the TE score, except for the number of years in school 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 (Appendix 1).

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%)
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

VRS = TE scores under variable returns to scale
CRS = TE scores under constant returns to scale
SE = scale efficiency score
Source: Calculated by the author using the DEA 2.1 program

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 to increase its TE.

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

In addition, there is a difference in the TE between the two study areas. The households in Soc Trang have higher TE than those in Can Tho. Specifically, rice yield in Soc Trang is almost 10 percent higher than in Can Tho (see Appendix 2). According to interviews with agricultural experts and agricultural extension officials, the higher rice yield in Soc Trang is due to better irrigation networks and adoption of good production practices with the guidance of local agricultural officials.

Stochastic Frontier Analysis (SFA) Measure

Maximum likelihood estimates (MLE), the parameters of the stochastic frontier, and the inefficiency model are presented in Table 5. The significance of $\gamma = 0.000$ and $\sigma^2 = 0.0144$ are (approximately zero) at 1 percent. 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 percent) at 7.779 from the χ^2 probability table. Hence, the null hypothesis is rejected. This indicates that the coefficients of the frontier production function are significantly different from the average production function estimated with the MLE model (Collie et al. 1998). Although there

Table 4. Determinants of the technical efficiency for the rice households

Model	Coefficient	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

is collinearity in some independent variables (e.g., plot size, seed, fertilizers), the indicators of tolerance and VIF found in Appendix 3 show 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 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 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.

Most advanced rice-farming practices are intended to reduce (inorganic) fertilizer use, minimize production costs, and lessen agriculture's negative environmental effects.

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

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

* significant at 10 percent level; ** significant at 5 percent level; *** significant at 1 percent level
Source: Calculated by the author using Frontier 4.1 program

For example, by practicing row seeding, a farmer can reduce the amount of seed needed by 80-120 kilograms per hectare and the labor requirement for seeding. By following IPM, a farmer would spend less on fertilizers and pesticides, but the amount (or costs) saved is usually underestimated.

For the technical inefficiency function, the estimated coefficients are significant at various levels. 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, farmers' experience has a statistically significant effect on the technical inefficiency of rice-growing households. As discussed in the DEA result, the farmers' experience does not 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 addition to satisfying its objectives, this study was able to provide an appropriate tool for measuring the TE of rice-producing farmers in the Mekong Delta. In addition, it was able to determine the important factors influencing the farmers' TE and identify the potential determinants of farmers' inefficiency in the study sites.

CONCLUSION

Using the tools DEA and SFA to estimate the technical efficiency of 261 rice-producing households in the 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 adopt advanced rice farming practice more than the traditional, with the guidance and encouragement of local agricultural officials. As a result, the average score of scale efficiency for the advanced rice-farming models is higher. Another finding is that 209 out of 261 households obtained an increased return to scale (RTS) while only 20 in the survey showed decreased RTS.

Second, the SFA results identified the determinants of the TE and inefficiency of rice-farming households. Plot size, costs of seed, and hired labor have significant positive effects on the TE of the households.

Finally, these results of estimation are important to understand the impacts of adopting advanced rice farming to rice-producing households. These may help local policymakers 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.

ACKNOWLEDGEMENT

Many thanks to Prof. Walter Nonneman of the Department of Economics, Antwerpen University who gave the author technical advice for the first draft. The author would like to express gratefulness to the two anonymous referees for their valuable comments and to the editors for their assistance.

APPENDICES

Appendix 1. Testing collinearity of DEA model

Testing Collinearity[a]

Model		Correlations			Collinearity Statistics	
		Zero-order	Partial	Part	Tolerance	VIF
1	Schooling	0.013	0.014	0.013	0.867	1.153
	Experience	-0.180	-0.169	-0.161	0.920	1.088
	Model (1: Advanced; 0: Traditional)	0.244	0.213	0.205	0.961	1.041
	Location (1:CT; 0: ST)	-0.197	-0.156	-0.149	0.903	1.107

a. Dependent Variable: Technical Efficiency Score
Note: CT= Can Tho City; ST= Soc Trang Province

Appendix 2. Differences in rice yield between Can Tho and Soc Trang

Descriptives

Location	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
Cantho	161	714.4534	80.47018	6.34194	701.9287	726.9781	500.00	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 0.4	1	849427 0.410	103.926	0.000
Within groups	2116904	259	8173 0.374		
Total	2966331	260			

Robust Tests of Equality Means

Yield	Statistic (a)	df1	df2	Sig
Brown-Forsythe	92.173	1	171.018	0.000

[a] Asymptotically F distributed

Appendix 3. Testing collinearity of SFA model

Testing collinearity[a]

Model		**Correlations**			**Collinearity statistics**	
		Zero-order	**Partial**	**Part**	**Tolerance**	**VIF**
1	LogPlot size	0.983	0.901	0.342	0.109	9.191
	LogSeed	0.859	-0.141	-0.023	0.189	5.292
	LogFertilizer	0.879	-0.047	-0.008	0.145	6.914
	LogPesticide	0.831	0.061	0.010	0.244	4.102
	LogOthers	0.719	0.106	0.018	0.463	2.158
	LogHirelabor	0.437	-0.197	-0.033	0.633	1.579
	LogFamilylabor	0.054	-0.039	-0.006	0.924	1.083
	Schooling	-0.077	-0.067	-0.011	0.827	1.210
	Experience	0.140	-0.147	-0.025	0.853	1.173
	Farming	-0.111	-0.228	-0.039	0.834	1.200

[a]Dependent Variable: Logoutput

REFERENCES

Aigner, D., C.A.K. Lovell, and P. Schmidt. 1977. Formulation and Estimation of Stochastic Frontier Production Function Models. *Journal of Econometrics*, 6 (1): 21-37.

Banker, R.D., A. Charnes and W.W. Cooper. 1978. Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis. *Management Science*, 30 (9): 108-109.

Binh, T.V. 2007. Establishing Agricultural Economic Models in Nhon Nghia Commune, Phong Dien District, Can Tho City.

Bordey, H.F. 2004. *Socio-economic Evaluation of Hybrid Rice Production in the Philippines*. Science City of Muñoz, Nueva Ecija, Philippines: Philippine Rice Research Institute.

Charnes, A., W.W. Cooper, and E. Rhodes. 1979. Measuring the Efficiency of Decision-making Units. *European Journal of Operational Research*, 3 (4): 429-441.

Chengappa, J., A. Janaiah, and M.V.S. Gowda. 2003. Profitability of Hybrid Rice Cultivation: Evidence from Karnataka. *Economic and Political Weekly*, June 21: 2531-2534.

Chen, Y. and A.I. Ali. 2002. Output-input Ratio Analysis and DEA Frontier. *European Journal of Operational Research*, 142 (3): 476-479.

Coelli, T.J., D.S.P. Rao, and G. Battese. 1998. *An Introduction to Efficiency and Productivity Analysis*. Dordrecht, the Netherlands: Kluwer Academic Publishers.

Den, D.T., A. Tihomir, and M. Harris. 2007. "Technical Efficiency of Prawn Farms in the Mekong Delta, Vietnam". Paper contributed to the 51st AARES Annual Conference, 12-15 February, Queenstown, New Zealand.

Farrell, M.J. 1957. The Measurement of Productive Efficiency. *Journal of the Royal Statistical Society*, Series A (General), 120 (3): 253 - 281.

Ellis, F. 1993. Peasant Economics: Farm Households and Agrarian Development (2nd ed.). Cambridge, UK: Cambridge University Press.

Hien, N.T.M. 2003. A Study on Technical Efficiency of Rice Production in the Mekong Delta, Vietnam by Stochastic Frontier Analysis. *Journal of the Faculty of Agriculture*, 48 (1/2): 325-357.

Khuda, B., H. Ishtiaq and M. Asif. 2005. Impact Assessment of Zero-tillage Technology in Rice-Wheat System: A Case Study from Pakistani Punjab. *Electronic Journal of Environmental, Agricultural and Food Chemistry*, 4 (6): 1132-1137.

Kim, H. 2010. Vietnam's Rice Export in 2009 Reaches 6 million tons. *Saigon Economic Times*. http://www.thesaigontimes.vn/Home/diendan/bandocviet/28680/ (accessed 17 January).

Kompas, T. 2002. Market Reform, Productivity and Efficiency in Vietnamese Rice Production. Canberra, Australia: National Center for Development Studies, Asia Pacific School of Economics and Management, Australian National University.

Linh, H.V. 2007. "Efficiency of Rice-farming Households in Vietnam: a DEA with Bootstrap and Stochastic Frontier Application". Paper presented at the 87th Southwestern Economics Association Annual Meeting, 14-17 March, New Mexico, USA.

Meeusen, W. and V.D. Broeck. 1977. Efficiency Estimation from Cobb-Douglas Production Functions with Composed Error. *International Economic Review*, 18 (2): 435-444.

Minot, N. 2003. *Income Diversification and Poverty in the Northern Uplands of Vietnam*. Washington DC, USA: Markets, Trade, and Institutions Division, International Food Policy Research Institute.

Nhut. Q.M. 2007. Allocation and Cost-efficiency Analysis of Selected Farming Patterns Within and Outside Boundary Irrigated Systems in Tri Ton and Cho Moi districts, An Giang Province (Mekong River Delta, Vietnam), Center for Asian Studies Discussion Paper Vol. 54. Antwerpen University. Antwerp, Belgium.

Oladele. O.I. and J.I. Sakagami. 2004. Impact of Technology Innovation on Rice Yield Gap in Asia and West Africa: Technology Transfer Issues. Tsukuba: Development Research Division, Japan International Research Center for Agricultural Sciences.

Richard, T.Y and E.G. Shively. 2007. Technical Change and Productive Efficiency: Irrigated Rice in the Philippines. *Asian Economic Journal*, 21 (2): 155–168.

Soc Trang Agricultural Extension Center. 2004. Production Efficiency of the IPM-based Rice Farming. Annual report. STAEC, Soc Trang province, Viet Nam.

Son, N.P. 2010. Socio-economic Efficiency and Development Potential of Artermia Production on Salt-based Area in the Mekong Delta, Viet Nam, PhD Dissertation, Antwerpen University.

Tijani, A.A. 2006. Analysis of the Technical Efficiency of Rice Farms in Ijesha Land of Osun State, Nigeria. *Agrekon*, 45 (2): 126-135.

Tran, T.U. 2002. The Impact of Green Revolution on Rice Production in Vietnam. Paper presented at the Workshop on Green Revolution in Asia and its Transferability to Africa, 8-10 December, Tokyo, Japan.

Vietnam General Statistical Office. 2003 and 2004. Some Indicators in Agriculture, Forestry, Fishery. Retrieved 15 September 2005 from the World Wide Web at http://www.gso.gov.vn