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Assessment of technical, economic, and allocative efficiencies of shrimp farming in the Mekong Delta, Vietnam

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Abstract

This study applied a stochastic frontier production model to analyze the technical (TE), allocative (AE), and economic (EE) efficiencies of intensive shrimp farming households, and to identify socioeconomic and shrimp farm-specific factors (farm size, labor, feed, seed, chemicals/medicine) that influence the TE, AE, and EE of shrimp production in the Ca Mau, Ben Tre, Bac Lieu, and Tra Vinh provinces of the Mekong Delta, Vietnam. The AE was calculated based on TE and EE. The stochastic frontier production and cost function model were used to evaluate the EE and TE at the shrimp farming household level. The results showed that the mean TE, AE, and EE of shrimp farming systems were 75%, 68.5%, and 61.4%, respectively. Age, gender, education, experience, cooperatives, and technical training significantly impacted the efficiency of shrimp production. The results suggest that shrimp farmers can improve shrimp productivity and EE by decreasing feed cost (FEE) and medicine/chemical cost (MED) of farm inputs. The study showed that shrimp farmers who participated in training activities, cooperatives, or management boards of aquaculture associations were more technically efficient than other farmers. The findings of this study provide essential information about the TE, AE, and EE of shrimp production, which can help local policy makers and shrimp farmers in the region to make better decisions on how to improve the EE and sustainability of shrimp production in the future. There is a need for recommendations on how to improve policies, technical guidance, and training courses on feed management and feeding practices, water quality, and disease management, to help shrimp farmers in the coastal provinces of the Mekong Delta to improve their shrimp production efficiencies in the future.

KEYWORDS
allocative efficiency, economic efficiency, productive efficiency, shrimp farming, technical efficiency

1 | INTRODUCTION

The rapid expansion of intensive shrimp farming has helped Vietnam to become the third-largest shrimp production nation, after China and Thailand, in the world. The Mekong Delta is the main region for aquaculture and agricultural food production in Vietnam (World Bank, 2017). Shrimp production in this region plays an important role in not only contributing to local livelihoods through income and national export revenue, and also contributing to international food security (MARD, 2019; Tipparat et al., 2019).

The Directorate of Fisheries (D-Fish) of Vietnam reported that the total area of brackish water shrimp farming in 2021 was estimated at 740,000 ha, of which black tiger shrimp, *Penaeus monodon*, farming was about 630,000 ha, while the area of whiteleg shrimp, *Litopenaeus vannamei*, farming was approximately 110,000 ha. The total production of black tiger shrimp and whiteleg shrimp in 2021 reached approximately 277,500 tons (30.2%) and 642,500 tons (69.8%), respectively (D-Fish, 2021). In recent years, intensive farming of these two shrimp species has expanded rapidly in the Mekong Delta region, improving local livelihoods, income, and national export revenues (Joffre et al., 2015). Although the expansion of intensive shrimp farming areas can provide many employment opportunities that contribute to the increase of farmers' net income, generating high profits through exports, it is also one of the main causes contributing to a significant reduction of mangrove areas, and associated environmental degradation and pollution, which has affected the shrimp industry itself (Da et al., 2015; de Graaf & Xuan, 1998; Duy et al., 2021; Tovar et al., 2000; World Bank, 2017). In addition, the impacts of long-term environmental degradation, weather conditions, and climate change (sea-level rise, drought, saline intrusion, irregular weather) also create economic losses and can be costly to society (Anh et al., 2010; Kiet & Fisher, 2014; Le et al., 2021; Merino et al., 2010). The outbreak of shrimp disease is one of the main issues leading to high cost of chemicals for water treatment, water exchange, and antibiotics for shrimp disease control, and demands comprehensive management to maintain high shrimp productivity. Therefore, it is essential to identify new forms of production to expand and develop this aquaculture production sector in a more environmentally sustainable and economically efficient manner (Le et al., 2021). Specifically, improved shrimp production at the farm level is one of the ways to reduce environmental pollution, increase resource efficiency and increase output in shrimp production without increasing the number of inputs and investment costs (Sharma, 1999).

There is a lack of studies that evaluate the resource-use efficiency and production efficiency of shrimp farming in the Mekong Delta, and more information about this could provide guidance on how to expand the shrimp production industry in Vietnam. A few studies have focused on cost efficiency analysis for *Litopenaeus vannamei* farming in the Khanh Hoa province (Huy & Thang, 2013); technical and financial aspects of shrimp intensive models in the Ca

Mau, Bac Lieu, and Soc Trang provinces (Mai et al., 2014); production efficiency comparison between rice-whiteleg shrimp and rice-tiger shrimp farming in the Kien Giang province (Thai et al., 2015); livelihood capabilities and pathways of shrimp farmers in the Mekong Delta (Ha et al., 2013), and economic characteristics of extensive shrimp farms in the Mekong Delta (Brennan et al., 2000).

Farrell (1957) suggested that measuring technical (TE), allocative (AE), and economic (EE) efficiencies are important factors for the productivity and output growth assessment of technical innovations. Coelli et al. (2005) conceived that farms could increase the output growth or increase their farm productivity by making more efficient use of inputs, operating closer to the technology and production frontier. Sharma and Leung (2003) and Hatch and Tai (1997) reported that production frontiers had been used for efficiency measurement of agriculture and other industries, but applications of production economics/production frontiers in aquaculture production are very limited. Therefore, empirical analysis identifies factors affecting the TE, AE, and EE is important to determine the benefits that can be obtained when improving shrimp production with given technological innovations. The objectives of this research were to investigate the main factors affecting the shrimp production output and estimate the TE, AE, and EE in shrimp production systems. It is expected that the findings of this study can help shrimp farmers in Vietnam's coastal provinces to implement more efficient shrimp production strategies in the future.

2 | MATERIALS AND METHODS

2.1 | Data collection

A field survey was undertaken during September 2019–December 2019 with a total of 350 households in seven villages from the four provinces. A total of 125 shrimp households (35.5%) in the Ca Mau province, with 57 households (16.3%) in the Bac Lieu province, 105 households (30%) in the Tra Vinh province, and 63 households (18%) households in the Ben Tre province were selected for the survey of this study (Figure 1). These provinces were selected because of the common occurrence of coastal brackish water aquaculture (central inland shrimp aquaculture production), rich fisheries, and mangrove forests. It constitutes a key area for intensive whiteleg shrimp production and contributes with approximately 60% of the total annual shrimp production in Vietnam (GSO, 2019; VASEP, 2019).

The primary data on shrimp pond farming systems were collected by using a structured questionnaire, observations, and informal discussions. The structured questionnaire was drafted, checked, and revised by the authors, and included some key questions on general information about shrimp households (household's farm land size, labor, farmer age, gender, educational level, ethnicity, experience of shrimp farming operations, participation in cooperatives and training in shrimp farming) and investment costs (seed, feed, chemical/medicine cost, fuel/electricity, farming operation, credit access, etc.). A total of 350 shrimp households were provided with the structured questionnaire with assistance from local agriculture technician staffs in each district, who also collected the questionnaire after 30 days. Three hundred nineteen households (approximately 91.1%) completed the questionnaire, but only 306 households (approximately 87.4%) provided valid answers and enough detailed information to be used in the analysis of this study. The exclusion of these invalid answers also helped to eliminate obvious outliers. The model assumptions and the efficiency indices in this study were predicted by using the FRONTIER 4.1 software (Coelli, 1996).

2.2 | Theoretical and empirical analysis

2.2.1 | Theoretical

According to Hatch and Tai (1997), the frontier production function approach defines the TE in two ways: (1) input-oriented, which is defined as a set of inputs to achieve maximum output; and (2) output-oriented, which is defined as

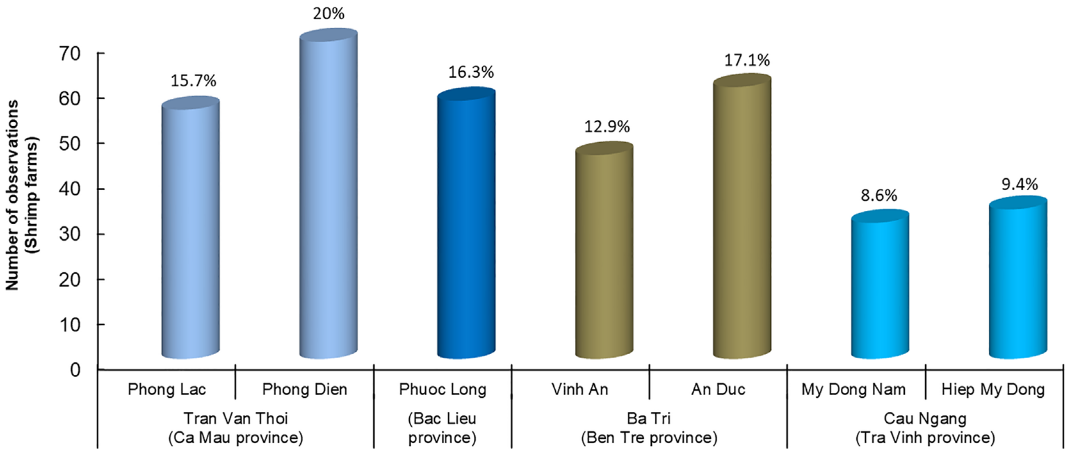

FIGURE 1 The total number and proportion of shrimp farms in seven villages from four selected districts in Bac Lieu, Ben Tre, Tra Vinh, and Ca Mau provinces that were surveyed in 2019 in the Mekong Delta of Vietnam.

a minimum set of inputs required to produce a given output. Farrell (1957) was the first to propose the concept of TE. TE is defined as the minimum amount of inputs that will produce a given level of output. Some scholars such as Aigner et al. (1977) and Meeusen and van Den Broeck (1977) developed the stochastic frontier production function to measure the TE of production, which is the most common approach (Coelli et al., 2005; Rahman, 2003). Therefore, the stochastic frontier production function was applied in this study to identify the factors affecting shrimp yield and to assess the efficiency of shrimp farmers in the Mekong Delta, Vietnam.

The stochastic frontier production model is presented as follows:

$$Y_i = f(X_{ij};\beta) + \varepsilon_{ij}, \tag{1}$$

where Y_i denotes the output for the ith shrimp farm (i = 1, 2, ..., n); X_{ij} is a (1 × k) vector of factor inputs of the ith shrimp farm, and β is a (k × 1) vector of unknown parameters to be estimated, and ε_{ij} is the error term, and it is defined as follows:

$$\varepsilon_{ij} = v_{ij} - u_{ij}, \tag{2}$$

where v_{ij} is assumed as a random error that is independently and normally distributed as N (0, $\sigma^2{}_v$) and identically distributed.

The next component u_{ij} is a positive normally distributed random variable of the form (0, $\sigma^2{}_u$) related to the technical inefficiency. This component allows the actual production to fall below the frontier; however, it does not attribute all short falls in the output from the frontier as inefficiencies.

Hence, the production frontier is written as follows:

$$Y_i = f(X_{ij};\beta) + v_{ij} - u_{ij}. \tag{3}$$

Therefore, the stochastic frontier production function is applied in this study and specified from Equation (1) as follows:

$$\ln Y_i = \beta_0 + \sum_i^n \beta_i \ln X_{ij} + (v_{ij} - u_{ij}). \tag{4}$$

Jondrow et al. (1982) proposed a method to measure the individual shrimp production inefficiency by indicating that the expected value of u for each observation can be obtained from the conditional distribution of *u*, and ε is a given value, the normal distribution for *v* and half normal for *u*; and is therefore determined by:

$$E(u_i|\varepsilon_i) = \sigma * \left[\frac{f^*(\varepsilon_i\lambda/\sigma)}{1 - F*(\varepsilon_i\lambda/\sigma)} - \frac{\varepsilon_i\lambda}{\sigma}\right], \tag{5}$$

where $\lambda = \sigma_u/\sigma_v$, $\sigma^2 = \sigma^2{}_u + \sigma^2{}_v$ while *F* and *f* represent cumulative distribution functions with standard normal density, evaluated at $\varepsilon_i\lambda/\sigma$. Subtracting *v* from Equation (4) generates the following function:

$$\ln Y_i^* = \beta_0 + \sum_{i=0}^{n} \beta_i \ln X_i - u_i = \ln (Y_i) - v_i, \tag{6}$$

where $\ln(Y_i^*)$ is defined as shrimp farm output adjusted for the statistical noise contained in v_i. From this Equation (6), we can compute the TE input vector, derive the cost frontier, and X_{it}, the minimum cost factor demand equation, which is used to estimate the EE, X_{ie}. The cost frontier is based on the duality function of a Cobb–Douglas production function, and the model is presented as follows:

$$\ln(Y_i^*) = \beta_0 + \sum_{i=0}^{n} \beta_i \ln P_i + \gamma \ln(Y_i^*), \tag{7}$$

where P_i is the *i*th input prices for shrimp production for *i*th farm and $\ln(Y_i^*)$ is total shrimp production output that is adjusted for any statistical noise. The efficiency indices in this study were calculated using the FRONTIER 4.1 software (Coelli, 1996).

From Equation (1), we can derive the quantities of inputs related to TE for any given level of $\overline{Y}$ output, by calculating the following two equations as follows:

$$\overline{Y} = g(X_i;\beta), \tag{8}$$

$$X_1/X_i = k_i, \tag{9}$$

where k_i is the ratio of the observed level of inputs X_i (i > 1) and X_1 at output $\overline{Y}$. Next, it is assumed that the production frontier in Equation (1) is in the form of a Cobb–Douglas function, which is why the dual cost frontier is derived and can be written in a general form as follows:

$$C = h(P, Y;\alpha), \tag{10}$$

where *P* is presented as a vector of input prices for the *i*th farm, *C* is the minimum cost to produce output *Y*, and α is a vector of the parameters. Applying Shephard's lemma, the system of minimum cost input demand equations can be calculated by differentiating the cost frontier with respect to each input price. Hence, the demand equation for the *i*th input (X_{di}) is equal to the following formulation:

$$\delta C/\delta P = X_{di} = f(P, Y;\varphi) \tag{11}$$

where φ is a vector of parameters. Based on the input demand equations, we can calculate the economically efficient input quantities, X_{ie}, by substituting the farm's input prices *P* and output quantity $\overline{Y}$ into Equation (4).

According to Farrell (1957), the production efficiency is divided into three components, including TE, EE, and AE. The TE is the ability to produce a given amount of output from a minimum amount of inputs, or the ability to produce a maximum amount of output from a given amount of inputs, for a given level of technology. The AE is the ability to choose an optimal amount of input where the marginal revenue product of the final unit of input is equal to the price of that input. EE or total efficiency is the product of TE and AE (Bravo-Ureta & Pinheiro, 1997; Farrell, 1957; Kopp, 1981). The input sources belong to socioeconomic factors, household characteristics (such as age of household head, experience of household head, training of household head per crop, education, gender, ethnicity, etc.) of intensive shrimp production in Vietnam are presented in Table 1.

These cost measures are the basis for calculating the EE and TE as follows:

$$\mathrm{TE} = (X_t.P)\,(X_a.P), \tag{12}$$

$$\mathrm{EE} = (X_e.P)\,(X_a.P), \tag{13}$$

According to Farrell (1957), the EE is equal to the product of TE and AE; hence, Equations (12) and (13) are used to calculate the AE as follows:

$$\mathrm{AE} = (X_t.P)\,(X_a.P)/(X_e.P)\,(X_a.P) = (X_t.P)\,(X_e.P) = (\mathrm{EE})/(\mathrm{TE}). \tag{14}$$

2.2.2 | Empirical analysis

The stochastic frontier production model

Some previous studies reported by Bravo-Ureta and Evenson (1994), Meeusen and van Den Broeck (1977) suggest that the production output of each agricultural farm can be assumed to be characterized by a Cobb–Douglas function. This is one of the most common production functions for estimating the relationship between inputs and outputs from each agricultural farm. In addition, the form of the Cobb–Douglas function can help to separate the stochastic frontier production for shrimp using maximum likelihood procedures. From Equation (6), the stochastic frontier production function was estimated as follows:

$$\ln(Y_i) = \beta_0 + \beta_1 \mathrm{lnSIZ} + \beta_2 \mathrm{lnLAB} + \beta_3 \mathrm{lnSEE} + \beta_4 \mathrm{lnFEE} + \beta_5 \mathrm{lnMED} + \beta_6 \mathrm{lnFUE} + \varepsilon_i, \tag{15}$$

where Y_i = shrimp yield of *i*th farmer in metric ton per 1000 m^2, LAB is defined as the number of employees per 1000 m^2, SEE is the cost of the seed used per 1000 m^2, FEE is the amount of money that shrimp farmers buy for 1 kg of feed, MED is the amount of money that shrimp farmers use to buy medicine and chemical for use on 1000 m^2. FUE is the cost that shrimp farmers pay for fuels (or electricity, gasoline) to manage the crop, and ε_i is the composed error term defined in Equation (7).

EE model

Bravo-Ureta and Evenson (1994) argued that EE includes TE and AE. Analyzing shrimp farms or shrimp farmer characteristics with TE, AE, and EE indices separately provides an important way to understand factors that affect farming efficiency. One approach is to conduct a simple nonparametric analysis or calculate the correlation coefficients known as the "second step" method. For a deeper understanding of this matter, the following models were used:

$$\mathrm{EFF} = \delta_0 + \delta_1 \mathrm{AGE} + \delta_2 \mathrm{EXP} + \delta_3 \mathrm{EDU} + \delta_4 \mathrm{CRE} + \delta_5 \mathrm{MAR} + \delta_6 \mathrm{TRA} + \delta_7 \mathrm{GEN} + \delta_8 \mathrm{ETH}, \tag{16}$$

TABLE 1 Component and variable definition with relevant references

Variables	Definition	Literatures	Expected signs
The variables used in the technical efficiency model			
Household's farm size (SIZ)	Size of the land owned by the household for shrimp production	Huy and Thang (2013), Thong and Phuong (2015)	+
Labor (LAB)	Number of workers directly involved in household shrimp farming	Huy and Thang (2013), Thong and Phuong (2015)	+/−
Seed cost (SEE)	The cost of seed that the household uses for one crop	Huy and Thang (2013), Vanh et al. (2016)	-
Feed cost (FEE) (kg)	The cost of feed that the household uses for one crop	Huy and Thang (2013), Mai et al. (2014), Vanh et al. (2016)	-
Medicine/chemical cost (MED)	The cost of Medicine/chemical that the household uses for one crop	Mai et al. (2014), Vanh et al. (2016)	-
Fuel cost (FUE)	The cost of fuel that the household uses for one crop	Vanh et al. (2016)	-
The variables used in economic efficiency model			
Age of household head (AGE)	Age of head of household by year of the survey	Tung and Phuong (2015), Thai et al. (2015)	+
Experience of household head (EXP)	Number of years by the household head in the aquaculture sector	Thong and Phuong (2015), Mai et al. (2014)	+
Education (EDU)	Number of schooling years of the household head	Tung and Phuong (2015), Thai et al. (2015)	+
Credit access (CRE)	Households participating in credit loans (yes = 1, no = 0)	Thong and Phuong (2015), Vanh et al. (2016)	-
Cooperative (COO)	Number of times a household joined a cooperative in a year	Duy (2017)	+
Training of household head (TRA)	Number of times the household head attended training	Thong and Phuong (2015)	+
Gender (GEN)	Gender of household head (male = 1, female = 0)	Trinh and Nghi (2010), Nghi et al. (2011), Duy (2017)	+/−
Ethnicity (ETH)	Ethnicity (Kinh = 1, others = 0)	Trinh and Nghi (2010), Nghi et al. (2011), Duy (2017)	+/−

where EFF is the TE, AE, or EE of shrimp farmers calculated in the previous frontier functions, using the two-limit Tobit procedure for the TE, AE, and EE computational models in Equation (16). Hossain (1988) suggested that the efficiency indices are bounded between 0 and 100. Hence, the results obtained from the two-limited Tobit models will be discussed in the following sections.

3 | RESULTS AND DISCUSSION

The summary statistics of the variables used for the stochastic production analysis and for estimating the source of efficiencies are shown in Table 2. The results show that the area of shrimp pond farming systems in the selected area ranged between 800 and 15,000 m^2, with a mean of 6.430 m^2. The mean farm and pond size of shrimp pond farmers

TABLE 2 Descriptive statistics for variables used in this study

Variables	Units	Mean	SD	Min	Max
Variables used in the technical efficiency model					
Household's farm size (SIZ)	Area (1000 m^2)	6.4	3.2	0.8	15
Labor (LAB)	Person	1.5	0.3	0.5	2.0
Seed cost (SEE) per crop	Thousand VND	7.3	0.7	7.1	7.5
Feed cost (FEE) (kg) per crop	Thousand VND	35.0	2.0	30	38
Medicine/chemical cost (MED) per crop	Thousand VND	7.4	1.0	5.5	9.8
Fuel cost (FUE) per crop	Thousand VND	4.5	1.3	3.2	7.6
The variables used in economic efficiency model					
Age of household head (AGE)	Years	43.9	5.0	24	67
Experience of household head (EXP)	Years	10.1	4.0	1	27
Education (EDU)	Years	7.5	3.5	5	16
Credit access (CRE)	Dummy	0.6	0.2	0	1
Cooperative (COO)	Number	0.4	0.1	0	1
Training of household head (TRA) per crop	Times	1.9	0.2	0	4
Gender (GEN)	Dummy	0.7	0.03	0	1
Ethnicity (ETH)	Dummy	0.6	0.2	0	1

are 1.8 ± 0.7 (0.8–2.3) ha and 0.3 ± 0.03 (0.21–0.27) ha, respectively. This is similar to the range found in previous studies by Tipparat et al. (2019), Ha et al. (2013), and Le et al. (2021) and quite similar to the pond size of the intensive aquaculture pond farming systems in the coastal zones of Bangladesh (Joffre et al., 2010). However, the current shrimp pond farming area in this study is much lower compared with the pond farming areas in Malaysia (Islam et al., 2014).

Sharma and Leung (2003) found that for extensive and semi-intensive shrimp farms, the farm size had a negative impact on the TE, whereas, for intensive shrimp farms, the farm size had a positive effect on the TE. The labor (LAB) input per crop in the surveyed farms was approximately 1–2 people (Table 2). The present study found that shrimp farming in the Mekong Delta depends heavily on local labor for their farm operations such as pond preparation, feeding, water treatment, pond management, and shrimp harvest. The number of laborers (1–2) in this study was quite similar to previous studies in the Khanh Hoa province reported by Long and Hien (2015), Huy and Thang (2013), and Le et al. (2021). The results of the present study show that the majority of the shrimp farms are managed by men, while the interviewed farmers represented several different ethnic groups including, Kinh, Khmer, Cham, and Hoa; Kinh people constituted the majority.

The average age and experience of shrimp farmers we 43.9 years old and over 10 years, respectively. This was higher than the age found in previous studies on shrimp farmers (Long & Hien, 2015; Trinh & Nghi, 2010). In general, farmer experience in shrimp farming was positively associated with the TE of shrimp production in this region (Tables 2 and 4). The average education level of shrimp farmers was 7.5 years (at secondary school level); however, some shrimp farmers had a university degree in aquaculture engineering (Bachelor degree). Over 60% of the households had access to formal credit from credit institutions. On average, shrimp farmers participated in 0.4 organizations per household (e.g., fishery extension associations, farm management boards, and cooperatives), indicating that many households did not participate in any of these organizations. On average, household heads participated in local training activities (shrimp health management and technology innovation) about 1.9 times per crop (Table 2).

The present study found that the highest costs in shrimp farming are commercial feed followed in descending order by medicine/chemicals, shrimp seed, and fuel. The feed prices in the selected study area varied among shrimp farmers and ranged from 30,000 to 38,000 VND/kg, with an average price of 34,900 VND/kg. Shrimp Post-larvae (PL_{15}), medicine/chemical, and fuel costs were approximately 7.27 ± 0.65 (7.10–7.46), 7.39 ± 1.02 (5.5–9.8), and 4.53 ± 1.27 (3.2–7.6) thousand VND per 1000 m^2, respectively. These investment costs were three times higher than those reported by Thong and Phuong (2015). In general, most shrimp farmers in the present study had a lack of cash, and therefore they had to buy shrimp feeds from local wholesale agents, who had comparatively high prices.

3.1 | Empirical model of the stochastic frontier production function

Table 3 presents the results of the maximum likelihood estimates (MLE) of parameters in the stochastic frontier, formulated by Equation (1), and a comparison of ordinary least squares (OLS) estimates of the average production function. The coefficient R^2 in this present study showed that 61% of the proportion of the total sample variation in the dependent variables was higher than the value of the R^2 coefficient in the study on shrimp production in the Mekong Delta of Vietnam reported by Mai et al. (2019), Ha et al. (2013), Lan (2013) and in costal communes of Central Vietnam reported by Minh et al. (2019).

The estimated coefficients of household farm size (SIZ), labor (LAB), feed (FEE), and medicine/chemicals (MED) in both the OLS and MLE estimates were statistically significant at 1% and 10% levels, respectively (Table 3). These results indicate that an additional increase in these variables will increase shrimp production, and that these variables are important for the success of shrimp farming in the region. For example, results of the present study found that the estimated coefficients of FEE and MED were statistically significant at 1% and 10% levels, respectively, indicating that shrimp production or output can be increased by 0.084% with a 1% increase in FEE and 0.233% with a 1% increase in MED. Sharma and Leung (2003) reported that improved water quality and feed management in shrimp farming had a positive effect on the TE of shrimp production and also found that the increase in labor input and farm size will increase the shrimp production by 0.017% and 0.045%, respectively (Table 3). The combined effects of FEE (0.084%), LAB (0.017%), SIZ (0.045%), and MED (0.233%) would increase shrimp production by 0.39%. The coefficient of SEE and FUE did not significantly affect shrimp production, based on both the OLS and MLE estimates.

TABLE 3 The OLS and MLE estimates for parameters of the stochastic frontier production function for the shrimp farmers in the Mekong Delta, Vietnam

Variables	Parameters	OLS Coefficients	OLS *t*-ratio	MLE Coefficients	MLE *t*-ratio
Constant	β_0	0.736	1.36	0.724	1.21
Household's farm size (SIZ)	β_1	0.045**	2.56	0.045**	2.64
Labor (LAB)	β_2	0.017**	3.18	0.017**	3.07
Seed cost (SEE)	β_3	0.268	2.84	0.273	2.89
Feed cost (FEE) (kg)	β_4	0.084*	1.95	0.084*	1.87
Medicine/chemical cost (MED)	β_5	0.233***	2.06	0.228***	1.98
Fuel cost (FUE)	β_6	0.151	3.77	0.151	3.85
R^2		0.61			
Model variance	σ_s			0.410	
Gamma	γ			0.722	
Log-likelihood				55.423	

Note: *, **, and *** are statistically significant at 1%, 5%, and 10%, respectively.

The results of the present study showed that the EE of shrimp production would increase if these key factors (FEE, LAB, and MED) were reduced (Table 3).

Jondrow et al. (1982) suggested that it is possible to obtain a gamma (γ), which is associated with the variance of technical inefficiency effects in the stochastic frontier from the maximum likelihood estimation. The estimated gamma (γ) in this study was approximately 0.722, which suggests that systematic influences are unexplained by the shrimp production factor for the dominant sources of random errors. Moreover, it indicates that 72% of the total variability of the shrimp yield was because of differences in the technical inefficiency among farmers. The proportion of the total variability in the present study was found to be higher than the proportion (64%) of the total variability of rice yield reported by Galawat and Yabe (2012). Moreover, shrimp production could be expected to be maximized if the technical inefficiencies among shrimp farmers are minimized. The dual cost frontier calculation derived from Equation (7) is given by the following formulation:

$$\ln C_i = 0.237 + (0.093)\ln P_{\text{siz}} + (0.110)\ln P_{\text{Lab}} + (0.036)\ln P_{\text{SEE}} + (0.801)\ln P_{\text{FEE}} + (0.051)\ln P_{\text{MED}}. + (0.824)\ln P_{\text{FUL}} + (0.442)\ \ln Y_i^{*}, \tag{17}$$

where C_i is the minimum cost of shrimp production for each farm, P_{siz} is the price of land rented by the shrimp farmer (if any), P_{Lab} wage rate of labor per day, P_{SEE} is the price of seed, P_{FEE} is the price of feed, P_{MED} is the price of medicine, P_{FUE} is the price of fuel, and $\ln(Y_i^*)$ is total shrimp production output that is adjusted for any statistical noise.

The important variables in the research model used in the stochastic marginal production function are presented in Table 4. Table 4 also shows the results of the percentage distribution and frequency of TE, AE, and EE of shrimp farmers in the selected provinces. The results from Equations (7) and (12) of this study indicate that the AE indices of shrimp farmers ranged between 2.4% and 94.1%, with a mean of 68.5%. The combined effect of the TE and AE gives the EE level among the farmers in this study. The TE indices of shrimp farmers in the study area were approximately 75% (24.6%–98.5%), where the "best" practice farmer operated at 98.5% efficiency, while the "worst" practice

TABLE 4 Frequency and percentage distribution of technical (TE), allocative (AE), and economic efficiency estimates (EE) of shrimp farmers in the Mekong Delta, Vietnam

	Technical efficiency		Allocative efficiency		Economic efficiency	
Efficiency level (%)	No. farmers	%	No. farmers	%	No. farmers	%
<10	0	0.00	2	0.65	1	0.33
11–20	1	0.32	3	0.98	3	0.98
21–30	6	1.96	11	3.59	4	1.31
31–40	15	4.90	21	6.86	23	7.52
41–50	34	11.11	36	11.74	39	12.75
51–60	48	15.69	24	7.84	45	14.71
61–70	93	30.39	68	22.22	62	20.26
71–80	79	25.82	87	28.43	70	22.88
71–80	16	5.23	51	16.67	44	14.38
>90	14	4.58	3	0.98	15	4.90
Total	306	100	306	100	306	100
Mean (%)	75		68.5		61.4	
Minimum (%)	24.6		2.4		0.9	
Maximum (%)	98.5		94.1		79.8	

shrimp farmer operated at a 24.6% level of efficiency. This indicated that the average shrimp farmer in the study could save an average of 23.9% (i.e., 1–[75/98.5]) of the costs, if the shrimp farmer was to achieve the TE level of the most efficient farmer. Similarly, for the most technically inefficient farmer, he/she could realize cost savings of 75% (i.e., 1–[24.6/98.5]).

Although farmers in the Mekong Delta are relatively efficient, there exist clear opportunities to increase their efficiencies by 25%, given the prevailing current set of inputs, prices, and technology. The mean EE indices in this study were 61.4%, ranging from 0.9 to 79.8% (Table 4). This indicates that if the average farmer in the study could reach the EE level of the most efficient farmer, he would save 23.1% of the costs (i.e., 1–[61.4/79.8]). Similarly, the most economically inefficient farmer can gain an EE of 98.9% (i.e., 1–[0.9/79.8]). The TE indices of shrimp farmers in the Mekong Delta can be considered as high, which is the primary reason why the allocative inefficiency among farmers needs more attention in order to improve the EE, because it is composed of the AE and TE indices. The mean EE found in the present study was in good agreement with the average EE values found in shrimp production farming systems in the Soc Trang and Kien Giang provinces (Tu et al., 2021).

3.2 | Socioeconomic factors affecting farmer's efficiency

The results of the two-limited Tobit equation used for the estimation of the main socioeconomic factors affecting production efficiency in this study are presented in Table 4. The results show that the estimated coefficient of AGE shows a robust and positive relationship with EE and AE, but a negative relationship with TE at the 10% level, which implies that younger farmers are more efficient than older farmers. This result suggests that an increase in age leads to an increased technical inefficiency of shrimp farmers. This is in good agreement with a study reported by Hussain (1989) and Shehu et al. (2007). Moreover, Shehu et al. (2007) also explained that as farmers advance in age, their overall ability to monitor agricultural activities decreases, but at the same time, their experience increases, which had a slightly stronger positive effect.

The estimated coefficient for experience (EXP) of the household head had a statistically significant positive influence on TE, AE, and EE, which indicates that farmers with more farming experience tend to be more efficient in shrimp production. This could, to some extent, compensate for the slight decreased efficiency with age, as experience often increases with age (Shehu et al., 2007). One of the reasons for the positive contribution of the variable to TE, AE, and EE could be that farmers with more years of experience tend to become more efficient through "learning by doing" (Da et al., 2011; Shehu et al., 2007). Furthermore, increased experience by farmers may lead to better assessment of the importance and complexities of better farming decision, including efficient use of inputs. The results of the present study are in good agreement with some earlier studies on shrimp production in the Soc Trang, Bac Lieu, and Ca Mau provinces (Mai et al., 2014; Tung & Trinh, 2015).

The comparatively strong statistically significant effect of education (EDU) on TE, AE and EE indicates the importance of training and capacity building for improved farming strategies. The positive coefficient clearly showed that shrimp farmers with higher levels of education are more efficient than shrimp farmers with lower levels of education. The results also showed that farmers with a high level of education have a better ability to access, evaluate, and implement strategies for their improved farming and marketing. Previous studies also found and confirmed that there is a positive association between education level and TE, AE, EE (Kalirajan & Shand, 1986; Krishna & Grabowski, 1985; Phillips & Marble, 1986). However, several other studies also reported no statistically significant relationship between these variables (Bravo-Ureta & Evenson, 1994; Kalirajan, 1981, 1994; Phillips & Marble, 1986). Several recent studies found that young farmers in the Mekong Delta have received better formal education than older farmers and therefore they are better equipped to access information and understand new technologies, which in turn have helped to improve their shrimp production efficiencies (Lan, 2013; Thanh & Phuc, 2013; Thong & Phuong, 2015; Tung & Trinh, 2015).

TABLE 5 Two-limit Tobit equations to estimate technical efficiency (TE), allocative efficiency (AE), and economic efficiency (EE) of shrimp farmers in the Mekong Delta, Vietnam

		TE		AE		EE	
Variable	Parameters	Coefficient	SE	Coefficient	SE	Coefficient	SE
Constant	δ_0	0.351**	0.031	0.892***	0.047	0.541	0.034
AGE	δ_1	−0.027***	0.014	0.127**	0.079	0.895**	0.038
EXP	δ_2	0.036*	0.097	0.024*	0.013	0.055***	0.074
EDU	δ_3	0.242**	0.037	0.567***	0.035	0.127*	0.061
CRE	δ_4	−0.036	0.029	−0.652	0.043	−0.014	0.023
COO	δ_5	0.041*	0.072	0.335*	0.036	0.048***	0.028
TRA	δ_6	0.024**	0.065	0.488	0.054	0.982*	0.043
GEN	δ_7	0.012*	0.018	0.081**	0.041	−0.221	0.011
ETH	δ_8	−0.124	0.066	−0.465	0.094	0.012	0.029
Log-likelihood		63.87		87.54		72.17	

Note: *, **, and *** are statistically significant at 1%, 5%, and 10%, respectively.
Abbreviations: AGE, age of household head; COO, cooperative; CRE, credit access; EDU, education; ETH, ethnicity; EXP, experience of household head; GEN, gender; TRA, training of household head.

The participation in cooperatives (COO) also had a statistically positive influence on TE, AE, and EE, because organizations such as cooperatives provide farmers with the opportunities to learn and share information with other farmers, especially on how to improve farming strategies. The present study found that inefficiencies among shrimp farmers decrease when shrimp farmers join the management board of the shrimp clusters/cooperatives, because these farmers are more often offered opportunities to participate in training courses where shrimp farmers are taught about pond management, seed quality selection, water quality management, wastewater treatment and feed management, chemical/medicine use, among other topics. These results are similar to previous studies of the aquaculture/agriculture sector in Vietnam (Au, 2012; Huy, 2007; Thuy & Hang, 2013) and *Pangasius* catfish farming (Belton et al., 2011; Khiem et al., 2010).

The estimated coefficient of training (TRA) showed a robust and positive relationship with TE and EE (Table 5) and indicated that training is directly related to the productivity and EE of shrimp farmers as training helps shrimp farmers to become more efficient in terms of farm management practices and resource use. The study confirmed that shrimp farmers who attended farm practices related training were more technically efficient than other farmers, which also was consistent with the findings of Au (2012).

The estimated coefficient of gender (GEN) had a weak positive relationship with TE and AE. Some previous studies demonstrated that GEN has a significant effect on both TE, AE, and EE (Galawat & Yabe, 2012; Gbigbi, 2011; Rahman, 2000; Shrestha et al., 2016). This may indicate that men are more effective than women in certain aspects of shrimp farming, which could be because of the fact that shrimp farming so far has been dominated by men. Still, as in many sectors, management practices could probably gain from a more increased gender balance.

4 | CONCLUSION AND RECOMMENDATION

This study applied a stochastic frontier production model to analyze the TE, AE, and EE efficiencies of 306 intensive shrimp farming households, and to also identify socioeconomic and shrimp farm-specific factors (farm size, labor, feed, seed, chemicals/medicine) that influence on TE, AE, and EE of shrimp farmers in the Mekong Delta. A two-limit Tobit regression technique was applied for estimating three separate equations, where TE, AE, and EE were expressed as functions of eight farmer characteristics (age of household head, experience of household head, education, credit access, cooperative, training of household head, gender, and ethnicity). The results from the stochastic frontier production showed that the variables farmland, labor, feed, and shrimp seed had statistically significant effects on shrimp production.

This suggests that shrimp households should focus on these variables to improve shrimp productivity. Feed cost is the main variable with the strongest impact on shrimp farming production in the Mekong Delta because the feed cost is often the major cost (occupied about 70%–80% of total investment costs) in shrimp production. Therefore, it is recommended that shrimp farmers should follow the quality standards and recommendations for feeding procedures and feed quality (food conversion rate, FCR) to save costs. Farmers should also check for the quality of feed used in the different stages of shrimp growth to get a better feed conversion rate (FCR), to ensure good growth performance, water quality, and shrimp health.

The research found that the average levels of TE, AE, and EE of shrimp farming systems in the Mekong Delta, Vietnam were approximately 75%, 68.5%, and 61.4%, respectively. This shows that reduced investment costs and increased yields can be achieved through improved farming management practices. The results confirmed the importance of examining not only EE but also TE and AE, when measuring productivity of shrimp farming. Feed quality (FCR of shrimp), feeding practices, and farm management are critical factors for future increases in shrimp production and development of the aquaculture sector. Hence, research efforts directed toward the generation of new and more efficient technologies, with the aim to also improve the environment, which aquaculture depends on for sustainable production, should continue to be encouraged. One of the most significant findings of this study is that shrimp farmers who participate in organizations or cooperatives and attend training courses on farm management, including pond management, seed quality selection, water quality management, wastewater treatment, feed use and feeding practices, and chemical/medicine use, become more efficient farmers. Therefore, farmers, especially those who are not members of any organization/cooperative, are encouraged to attend training courses to improve their farming management skills. Hence, the authors suggest that both local and provincial government agencies such as the Department of Agriculture and Rural Development, Aquaculture and fisheries extension offices and universities should organize regular training courses and encourage shrimp farmers to participate as this can help to improve the overall efficiency and environmental awareness for a long-term and healthy production of shrimps in the Mekong Delta.

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CONFLICT OF INTERESTS

The authors declare no conflict of interest.

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