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Research Article

Technical Efficiency of Fishing Activities: A Case Study of Small-Scale Trawling in the Mekong Delta, Vietnam

Dang Thi Phuong,[1] Nguyen Thanh Long,[1] and Huynh Viet Khai[2]

[1]*College of Aquaculture and Fisheries, Can Tho University, Can Tho, Vietnam*
[2]*School of Economics, Can Tho University, Can Tho, Vietnam*

Correspondence should be addressed to Huynh Viet Khai; hvkhai@ctu.edu.vn

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This study estimated the technical efficiency of small-scale trawling in the Mekong Delta using a translog stochastic frontier production function model. Primary data were collected by interviewing the small-scale trawling vessels from January 2020 to May 2021 in the four coastal provinces (Soc Trang, Bac Lieu, Ca Mau, and Kien Giang) of the Mekong Delta. The results showed that the average technical efficiency of the surveyed fishermen was approximately 68.8%. Small-scale trawling vessels could increase their production by 31.2% if they operated at full technical efficiency. The captain's fishing experience, vessel size, the number of nets on a boat, cooperation for inputs, supplies, and problem-solving, fishing registration, operation distance, and the fishing grounds were the main factors influencing the technical efficiency. To improve the technical efficiency of the trawling industry, it is necessary to focus on training the captains in fishing techniques, upgrading and converting large-scale vessels, and linking the market channels for consuming the caught fishery products.

1. Introduction

Accounting for 9-10% of the total export value, the fisheries sector has played an essential role in Vietnam's economy and contributed to socioeconomic stability [1], especially in fisheries. In 2015, the fishing production was 3.1 million tons with a total export value of USD 2.2 billion [2], which increased by 26.5% and 54.5%, respectively, in 2021 [3]. In addition, marine capture fisheries create jobs for local people and supply vital protein sources [4, 5]. Located in the southern part of Vietnam, the Mekong Delta (MD) accounts for 17.7% of the population and contributes approximately 38.4% of wild fish catch and 26.1% of marine capture production in Vietnam [6]. Eight of the twelve provinces in the region are coastal provinces with diverse marine fishing activities, such as trawling, gillnets, and seine nets, which make up 60% of fishing vessels. In 2018, the MD's small-scale and inshore fisheries accounted for 53.3% of the total fishing vessels. Although it is difficult to define small-scale or commercial aspects of fisheries in Vietnam [7], they can be classified according to characteristics such as hull length and engine sizes. Furthermore, small-scale fishing provides approximately 80% of households' income and is a vital livelihood for local communities [8].

Small-scale trawling has caused the degradation of the coastal environment, particularly the seafloor, and the depletion of many populations due to bycatch [9]. A study by Pomeroy et al. [7] indicated that fisheries resources in Vietnam were already overexploited. Consequently, the Vietnamese government has restricted the number of small-scale fishing vessels, including trawlers, and encouraged offshore fishing [10]. The management includes controlling vessel registration, mesh size, engine capacity, and fishing licenses [11]. However, controlling small-scale fishing is unlikely due to a lack of human resources and capital. Information on the technical efficiency of small-scale trawling could provide an additional perspective on this fishing method and thus guide fisheries management [12, 13].

The stochastic frontier approach has been applied in previous studies of efficiency in fishing activities. For example, Kirkley et al. [14] were the first to use a stochastic frontier in fisheries and predicted the possible effects on technical efficiency of changes in limited entry and input restrictions for the Mid-Atlantic sea scallop fishery. Sharma and Leung [15] investigated the effects of vessel characteristics and targeted species on vessel technical efficiency in the Hawaiian longline fishery. Pascoe and Coglan [16] studied the contribution of unmeasurable inputs to overall technical efficiency in the English Channel fishing fleet. In Vietnam, efficiency analysis has been applied to several marine fishing methods, such as gillnetting in Da Nang [11] and trawling [13], but not for small-scale trawling in the Mekong Delta. Therefore, this study aimed to estimate the technical efficiency of this fishing method using a stochastic frontier model. Note that trawling accounts for 40% of the total fishing vessels in the Mekong Delta.

2. Methods

2.1. Stochastic Frontier and Inefficiency Model. Aigner et al. [17], Meeusen and van Den Broeck [18], and then Battese [19] were the first to develop stochastic production frontiers. The stochastic production frontier is one of the methodologies commonly used to describe the estimation of a production frontier, which is the frontier parametric estimation of efficiency. The specification can separate the effects of noise from the effects of inefficiency and conflate the effects of misspecification of functional form with inefficiency. The stochastic frontier production function can be expressed as

$$Y_i = f(x_i, \beta, v_i - u_i), \tag{1}$$

where Y_i is the output produced by firm i; x_i is a vector of inputs for the i^{th} firm; β is a vector of unknown parameters; and the error term v_i is assumed to be independently and identically distributed as $N[0, \sigma_v^2]$ random variables, independent of $u_{i,}$, and can be positive or negative. The error term u_i represents the technical inefficiency of the i^{th} firm. The common assumption of u_i is that it is nonnegative, independently distributed, and has nonnegative truncations (at zero) from the distribution $N(z_i\delta, {\sigma_u}^2)$. When $u_i = 0$, the i^{th} firm lies on the stochastic frontier, representing perfect efficiency. If $u_i > 0$, the i^{th} firm lies below the frontier and is technically inefficient [20–22].

Following Battese and Coelli [23], the random variable associated with technical inefficiency, u_i, is a function of firm-specific variables that are hypothesized to influence technical inefficiencies. The technical inefficiency function can be given by

$$u_i = z_i\delta + w_i, \tag{2}$$

where u_i is the technical inefficiency of firm i; z_i is the vector of firm-specific variables that may influence the efficiency of firm i; δ is the associated matrix of coefficients; w_i is distributed $N[0, \sigma_w^2]$.

The technical inefficiency determined by equation (1) is the ratio of actual output to potential frontier output. Jondrow et al. [24] determined the expected value of u_i given the value of $\varepsilon_i = v_i - u_i$ despite the fact that u_i cannot be directly observed. The technical efficiency of the firm i in equation (1) is calculated by $TE_i = \exp(-u_i)$. The technical efficiency score ranges from 0 to 1, with a higher score implying full efficiency. The parameters of the stochastic production frontier model and the technical inefficiency model are estimated in a one-step procedure using maximum-likelihood estimation (MLE). The parameters estimated include β and variance parameters such as $\sigma_S^2 = \sigma_u^2 + \sigma_v^2$ and $\gamma = \sigma_u^2/(\sigma_u^2 + \sigma_v^2)$. Here, σ_S^2 is the sum of the error variance. The value γ measures the total variation of output from the frontier attributed to the existence of random noise or inefficiency and is bounded between zero and one [25].

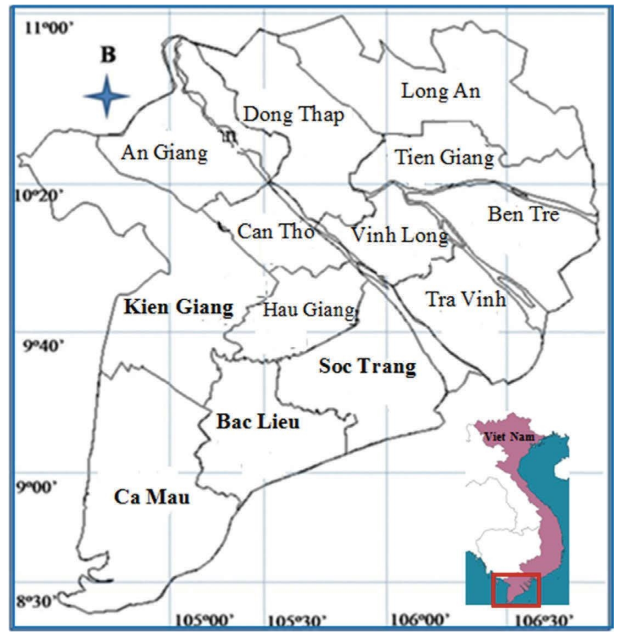

Figure 1: Research areas.

2.2. Data Collection. Trawling is an important occupation of the fishing industry in the Mekong Delta. In this fishing method, a fishing net is pulled through the bottom of the water by a vessel. Towing the net through the water allows for catching various fish species, particularly benthic species [26]. According to the Directorate of Fisheries, trawling with a vessel length ranging between 6 m and under 15 m was defined as small-scale fishing that operates near the coastline and inshore [27]. These were further classified into small vessels (from 6 m to less than 12 m) and medium vessels (from 12 m to less than 15 m).

The cross-sectional data used in the study were collected from January 2020 to May 2021. Two interviews were conducted with selected respondents from the four provinces using a structured questionnaire. The first interview was conducted between January 2020 and March 2020 with the key informant panel of senior specialists from the Department of Fishery. They were interviewed using a list of open-ended questions to collect secondary data on their fishing activities. After this step, the four coastal provinces of the MD were chosen for interviewing, including Soc Trang and Bac Lieu (representing the east coastal region) and Ca

Table 1: Input and output variables used in the study.

Variables	Mean	Standard deviation	Minimum	Maximum
(1) Output				
Average revenue per trip (million VND)	19.9	18.5	0.5	140.0
(2) Inputs				
Fishing day (day)	3.3	2.4	1.0	15.0
Crew member (person)[a]	3.2	0.9	2.0	6.0
Engine (HP)[b]	63.1	38.5	8.0	185.0
(3) Vessel and operator specific variable				
Experience (year)	16.26	7.82	2.0	40.0
Family crew (person)	1.76	0.84	0	5
Used time of vessel (year)	9.00	5.2	1.0	30.0
Vessel size (1 = medium, 0 = small)[c]	0.58	0.49	0	1
Mesh size (mm)	24.52	6.4	12.0	50.0
Net numbers (net)	2.73	1.25	1	6
Fishing ground (1 = west coast, 0 = east coast)	0.47	0.50	0	1
Operation distance from shore (nautical miles)	12.36	6.74	0.3	30
Gear registration (1 = yes, 0 = no)	0.83	0.37	0	1
Cooperation (1 = yes, 0 = no)	0.74	0.44	0	1

Notes: total number of observations (n) = 223. All economic values are in million VND (US$1 = 23.577 VND in 2021). [a]The crew members include the captain. [b]HP- a unit measure the engine power (HP–horsepower). [c]Medium vessel: 12-under 15 m in length; small vessel: 6-under 12 m in length.

Mau and Kien Giang (representing the west coastal region) (Figure 1). The second interview was conducted face-to-face from April 2020 to May 2021, using questionnaires for small-scale trawling vessels. The vessels were randomly selected from the lists provided by local authorities. The trawling vessels interviewed in this study were categorized as medium and small vessels, with a total of 223 observations (131 medium vessels and 92 small vessels). The questionnaire was designed with the skipper's characteristics (e.g., experience, education, crew member), the vessel's physical characteristics and fishing efforts (e.g., engine size, fishing days), yields (e.g., average revenue per trip), fishing costs (e.g., fuel, ice, labor, and other costs), and other information relating to fishing activities for the 2019 fishing season.

The descriptive statistics of all variables used for estimating the stochastic production frontier and technical inefficiency models are shown in Table 1. The average trawling vessel length was 12 m, ranging from 6.5 to 14.9 m. The vessel had been in use for a range of 1 to 30 years, with an average of 9 years. The trawling fishers had small boats with an average of 63.1 HP, and the crew size ranged from 2 to 6 persons. Depending on the size and capacity of a vessel, trawling fishers can go to sea for 1–15 days per trip, with an average of 3.3 days. The average net length was 22.1 m, varying from 8–45 m, and the mesh size for the cod-end was 24.5 mm. Fishers had an average age of 41-42 years old, ranging from 22–66, with an average fishing experience of 16.2 years. The distance to fishing grounds from their landing was 12.3 nautical miles. The total average revenue of the vessels differed considerably, ranging from 0.5 to 140 million VND per trip, with an average of 19.9 million VND per trip.

2.3. Empirical Model. The output measure presents certain challenges when modeling fisheries. Both the quantity and the value of the catch were used as the measure of efficiency due to the peculiarity of fishing. Some studies (e.g., [14, 28]) have used fishing yield for efficiency analysis, whereas others [11, 13, 16, 29, 30] employed revenue. Trawl fishing catches various species at different sizes. The prices greatly vary according to species and sizes, and therefore, using the average revenue per trip for the output measurement is reasonable in this case.

In previous studies, a wide range of inputs was used for efficiency analysis. The important inputs included capital, labor utilization, and capital utilization. In the short run, some of the inputs used in fishing are relatively unchanged, for example, vessel length and engine [13, 29]. However, the level of output of the vessels was a function of the capital utilization, in particular, the number of fishing days [31, 32]. Kirkley et al. [14] used the variables of the number of persons on the boat and the number of fishing days to represent labor and capital utilization, respectively. Squires et al. [28] used one of the inputs, e.g., the number of crew employed per vessel (representing a variable input), for the technical efficiency analysis of the Malaysian gillnet fishery. Truong et al. [11] used the variable costs, crew size, and net length to analyze the technical efficiency of the gillnet fishery in Da Nang, Vietnam. Herrero et al. [30] analyzed the Spanish-Moroccan deep trawl fishery, selecting days at sea, gross registered tonnage, and engine power as variables and tangible inputs. The choice of appropriate proxies for inputs is largely dependent on the data availability and type of fishing gear. For instance, engine power, crew size, and time of fishing are important inputs in trawl fishing [13, 30, 32], while vessel length, fishing gear, and days at sea are more important in longline and gillnet fishing [11, 28]. In this study, our data includes engine horsepower, crew size, and fishing days, thus providing proxies for both fixed inputs and labor and capital utilization.

In fisheries, the stochastic production frontier analysis could be appropriate for analyzing the technical efficiency of renewable resources, indicating that renewable resources have stochastic characteristics [11, 14, 15]. In addition, the output-oriented approach has also been most commonly used in fisheries, meaning fishers aim to maximize their revenue each trip [29]. Several potential functional forms can be used to specify the stochastic frontier; however, in most empirical applications, the desirable form is the translog function due to its flexibility, which could easily facilitate the calculation of individual values for technical inefficiency and efficiency [14]. The translog stochastic production frontier can be written as

$$\ln Y_i = \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_4 (\ln X_1)^2 + \beta_5 (\ln X_2)^2 + \beta_6 (\ln X_3)^2 + \beta_7 \ln X_1 * \ln X_2 + \beta_8 \ln X_1 * \ln X_3 + \beta_9 \ln X_2 * \ln X_3 + \nu_i - u_i, \quad (3)$$

where Y_i is the average revenue per trip (million VND/trip); X_1 is the total fishing days including days spent on travel (days/trip); X_2 is the number of persons on the boat including the captain (persons); X_3 is the engine (HP); $\nu_i - u_i$ is the combined error term.

The functional form of the inefficiency model can be specified as follows:

$$u_i = \delta_0 + \sum_{j=1}^{10} \delta_i Z_{ij} + \omega_i, \quad (4)$$

where u_i is the technical inefficiency of the trawl net vessel; $Z_{1,2,\ldots,10}$ are the vessel- and operator-specific variables. Variables are Z_1: experience-captain's trawl net fishing experience (years); Z_2: family crew (persons); Z_3: used time of vessel (years); Z_4: vessel size (1 denotes a medium size (length ranging from 12 to under 15 m), 0 denotes the small size (length ranging from 6 to under 12 m)); Z_5: mesh size (mm); Z_6: numbers of net on the boat (net); Z_7: fishing ground (1 denotes west coast, 0 denotes east coast); Z_8: distance from shore (nautical miles); Z_9: gear registration (1 denotes fishing certification, 0 denotes otherwise); Z_{10}: cooperation (1 denotes joined linkage between vessels in fishing; 0 denotes otherwise).

The appropriateness of the translog functional form of the model was tested against a Cobb–Douglas specification. These null hypotheses can be tested by using the following generalized likelihood ratio (LR): $LR = -2\{\ln[L(H_0)] - \ln[L(H_1)]\}$, where $\ln[L(H_0)]$ and $\ln[L(H_1)]$ are the values of the log-likelihood function under the null and alternative hypothesis, respectively. This has a chi-square (χ^2) distribution, with the number of degrees of freedom provided by the number of restrictions imposed.

The parameters of the stochastic production frontier and technical inefficiency models were estimated simultaneously using equations (3) and (4) and the maximum-likelihood estimation (MLE) program STATA 15 [33].

3. Results and Discussion

3.1. Parameter Estimates and Statistical Results. Generalized likelihood-ratio tests of the key null hypotheses involving the restriction on the parameters in the stochastic production frontier and technical inefficiency models are presented in Table 2. The first test is applied to check the existence of the Cobb-Douglas production function. The null hypothesis of jointed parameters equal to 0 ($\beta_4 = \beta_5 = \ldots = \beta_9 = 0$) and the restricted function are estimated. The second null hypothesis is that technical inefficiency effects were absent ($\gamma = \delta_0 = \delta_1 = \ldots = \delta_{10} = 0$). The third null hypothesis test is that all the parameters of the inefficiency model were considered, except the intercept at zero ($\delta_1 = \delta_2 = \ldots = \delta_{10} = 0$). From the results in Table 2, the model presented in Table 3 is the most appropriate. The null hypotheses were rejected.

Many variables were found to be significant in both the frontier and inefficiency models (Table 3). Regarding the parameter estimates for the stochastic frontier model, the coefficients of the fishing day and crew member variables were significant and had the expected positive signs, whereas the coefficient of the engine variable was significant and had a negative sign. It is implied that any increase in each mentioned variable would lead to higher production, except for the engine. Almost all the vessel- and operator-specific variables had a statistically significant impact on the technical inefficiencies, except for the family crew, vessel age, and mesh size variables. The estimated value of $\gamma = 0.469$, meaning that 46.9% of the differences between the observed output and the frontier level of output were caused by differences in fishermen's technical efficiencies, while the remaining variation is due to factors outside the fishermen's control. The result value was consistent with other efficiency studies on the trawl fishery [13, 32].

3.2. Technical Efficiency. The frequency distribution of the estimated technical efficiency scores relative to best practice frontier scores is illustrated in Figure 2. The results indicated that the estimated technical efficiencies for the small-scale trawl varied between 9.4% and 93.4%, with a mean efficiency of 68.8%. Studies by Sharma and Leung [15]; Kompas et al. [35]; Tingleg et al. [29]; Herrero et al. [30]; Pascoe et al. [32]; Van Nguyen et al. [13] also showed a large fluctuation of efficiency between 65% and 80%. Therefore, they could proportionally reduce their inputs by 31.2% and still produce the same amount of output. From this figure, there is a considerable range of efficiency in small-scale trawling. The majority of the vessels had a technical efficiency score of 0.8 to 0.9 (26.9%), followed by 18.8% of vessels with an efficiency score of 0.7 to 0.8. A small proportion of the observed vessels (8.1%) were operating with efficiency levels under 0.3, and 14.4% of the observed vessels were operating at a technical efficiency index above 0.9. Generally, the majority of small-scale trawl vessels have the potential to improve their

Table 2: Generalized likelihood ratio tests of the hypotheses for parameters of the stochastic production frontier and technical inefficiency models for the small-scale trawl net in the Mekong Delta.

Null hypothesis	Likelihood ratio	Degrees of freedom	Critical value χ^2	Decision
H_0: $\beta_4 = \beta_5 = \ldots = \beta_9 = 0$	11.62	6	10.645*	Reject H_0
H_0: $\gamma = \delta_0 = \delta_1 = \ldots = \delta_{10} = 0$	77.695	9	22.525***	Reject H_0
H_0: $\delta_1 = \delta_2 = \ldots. = \delta_{10} = 0$	77.694	10	23.209***	Reject H_0

Note: *** and * are statistically significant at 1% and 10%. The critical value for the second hypothesis has been calculated using the tables in Kodde and Palm [34].

Table 3: Parameters estimate of stochastic production frontier and technical inefficiency models.

Variables	Coefficient	t-ratio
(1) Stochastic production frontier		
Constant	2.297	1.75*
ln (*fishing day*)	1.601	3.22***
ln (*crew members*)	1.805	1.96**
ln (*engine*)	−1.083	−1.71*
ln (*fishing day*)* ln (*fishing day*)	−0.031	−0.37
ln (*crew members*)* ln (*crew members*)	−0.604	−1.33
ln (*engine*)* ln (*engine*)	0.176	2.04**
ln (*fishing day*)* ln (*crew members*)	0.060	0.26
ln (*fishing day*)* ln (*engine*)	−0.211	−1.47
ln (*crew members*)* ln (*engine*)	0.033	0.12
(2) Inefficiency model		
Constant	2.547	3.12***
ln (experience)	−0.276	−2.77***
ln (family crew)	0.032	0.20
ln (used time of vessel)	0.162	1.62
Vessel size (1 = medium, 0 = small)	−0.433	−1.94*
ln (mesh size)	−0.116	−0.52
ln (net numbers)	−0.449	−2.82***
Fishing ground (1 = west sea, 0 = east sea)	−0.410	−2.19**
ln (operation distance from shore)	−0.188	−2.42**
Gear registration (1 = yes, 0 = no)	−0.216	−1.66*
Cooperation (1 = yes, 0 = no)	−0.267	−2.07**
(3) Variance parameter		
Observation	223	
Log-likelihood	−117.17	
Wald χ^2 (9)	215.72	
σ_u^2	0.105	
σ_v^2	0.119	
$\sigma_S^2 = \sigma_u^2 + \sigma_v^2$	0.224	
$\gamma = \sigma_u^2/\sigma_S^2$	0.469	

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

technical efficiency. Table 4 shows that fishermen received approximately 19.9 million VND per trip for the actual revenue and 25.2 million VND per trip for the frontier revenue, implying a potential improvement of 5.3 million VND/trip. Vessels with a higher average technical efficiency per trip had higher fishing revenue. The technical efficiency level was over 0.9 for vessels that had the highest actual revenue, earning about 46.6 million VND per trip. Vessels with the lowest technical efficiency score (lower than 0.3) received the least revenue at an average of 1.5 million VND per trip.

As shown in Table 4, the average technical efficiency in fisheries is based on input usage. An increase in TE is accompanied by an increase in average revenue. It is shown that fishing vessels with a long fishing trip, three to four laborers on the boat, and a large engine power were found to be highly technically efficient. Fishing vessels with long fishing trips had higher technical efficiency. An explanation for this is that the vessels taking long fishing trips often accessed fishing groups that were further away, offering more resources for exploitation. The distribution of technical efficiency among the 68 fishing vessels, with estimated efficiency ranging from 0.6 to 0.8, had the number of fishing days ranging from 3.0 days to 3.3 days. The average technical efficiency of the 32 vessels that spent longer fishing trips (5.7 days) was higher than 0.9, while the 45 vessels with the lower technical efficiency (lower than 0.5) had fishing trips ranging from 1.0–1.6 days. It is noted that longer fishing trips increase fishing costs due to operating in a wider range of areas. An explanation for this is that the total costs incurred by each vessel per trip, including fuel, ice, and other miscellaneous

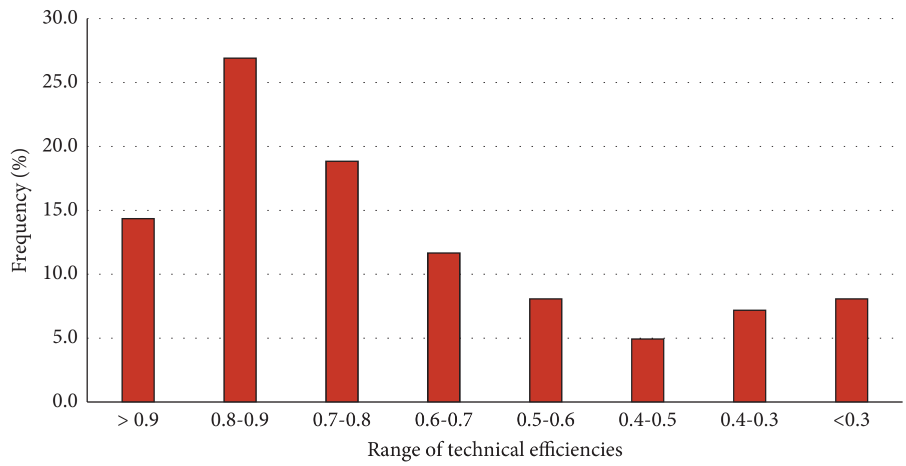

Figure 2: Frequency distribution of technical efficiencies for the trawling in the Mekong Delta.

Table 4: Inputs, actual revenue, and frontier revenue at different TE.

Efficiency	Observation	Fishing day	Crew size	Engine	Actual revenue	Frontier revenue
>0.9	32	5.7	4.0	93.6	46.6	50.9
0.8-0.9	60	4.2	3.6	81.8	27.1	31.5
0.7-0.8	42	3.3	3.4	56.0	17.9	23.8
0.6-0.7	26	3.0	3.2	52.2	11.7	18.0
0.5-0.6	18	1.9	2.8	41.0	7.2	12.9
0.4-0.5	11	1.6	2.7	56.0	5.0	10.7
0.3-0.4	16	1.6	2.6	33.4	3.4	9.7
<0.3	18	1.1	2.3	32.2	1.5	6.5
Average		3.3	3.2	63.1	19.9	25.2

Note. All economic values are in million VND (US$1 = 23.577 VND in 2021).

items, would increase along with the number of days spent fishing. According to fishing conditions, some trawlers could not spend more days due to their capacity, for example, their small vessel size and low engine power. Moreover, simple techniques for fish preservation posed a problem for fishermen. The quality of fish could be reduced because all fishermen used ice for fish preservation, thus reducing the price. High technical efficiency (up to 90%) was found for trips of approximately six days, bringing a revenue of 46.6 million VND per trip. The number of days at sea for trips with technical efficiency lower than 50% ranged from one to two days, generating 1.5–5.0 million VND per trip for actual revenue and 6.5–10.7 million VND per trip for frontier revenue. The crew member was found to have similar impacts to the fishing day. Vessels with the highest technical efficiency level (over 0.9) used more labor, an average of 4.0 persons, while vessels with the lowest technical efficiency levels had the least crew members, averaging 2.3 persons.

Regarding fixed input, namely engine power, the trend of the relationship between technical efficiency and this input was found to be opposite to the impacts of variable inputs. In trawling, engine power (HP) significantly contributes to fishing operations. During fishing operations, the opening of the net is completely dependent on the vessel's speed. In addition, the trawling vessel operates in different conditions such as counter-water currents, wind, and water depth. Therefore, the engine of the trawl vessel is one of the key factors of successful fishing. Hence, fishers tend to upgrade the engine of their vessels with the expectation of production improvement. However, the efficiency differences in engine power for small trawl vessels were unstable, whereas the medium's efficiency could be increased by expanding the engine.

The estimated output elasticities for the trawl vessel in MD showed that the fishing day, the crew member, and the engine were positive signs and less than one. The revenue elasticity of the fishing day was highest at 0.77, followed by the crew member (0.61) and engine (0.15). Regarding the returns to scale for trawl fishing in MD, known as the sum of output elasticities for all inputs, it was 1.53, implying that an expansion of fishing days, labor, and engine inputs by 1% would increase the revenue by 1.53%, consistent with those from previous studies (e.g., [11, 15, 36]). Therefore, the results indicated that increasing these inputs would result in a more than proportional increase in revenue.

3.3. *Factors Affecting the Efficiency.*

The estimated inefficiency model is presented in Table 3. Factors affecting efficiency could be categorized into five groups as follows:

3.3.1. *Captain's Characteristics.*

The fishing experience was likely to be a partial representation of the captain's characteristics. As expected, the fishing experience had a negative influence on technical inefficiency. The fishing experience of the captains was statistically significant at the 1% level, indicating that fishing experience was valuable. Captains with more years of experience in fishing are found to be more efficient than those with less experience. Pascoe and Coglan [16] found that the managerial inexperience of the captains on the boats could reduce fishing's technical efficiency. Similarly, Squires et al. [28] found that the gillnet vessels in Malaysia could improve their performance by increasing the captain's experience. The fishing experience variable appears to be an important human capital for increasing fishing productivity. Designing fisheries management policies should consider the level of fishing experience due to it being a hereditary occupation. This result also suggested that more family members of the trawl vessel were inefficient because the employed crew worked harder and had more responsibility for the vessel's operation, although the influence was not significant as the coefficient was relatively small. Similarly, Van Nguyen et al. [13] found that more employed crew members were more efficient, as the employed crew was generally paid.

3.3.2. Vessel Characteristics. One of the vessel's characteristics was the length of time it had been owned by the present owner. As expected, the length of time had positive effects on technical efficiency, quite similar to previous studies, which found that the length of time had a strong positive influence on the vessel's efficiency [11, 16]. It is explained that newer boats are more efficient than older boats, which could be because the older vessels require more energy consumption and cost for maintenance. This factor did not significantly influence the inefficiency at the 10% level of significance. In this study, the relationship between technical efficiency and vessel size is similar to the correlation between efficiency and a firm's scale [28]. Regarding the hull length of the vessel, the vessel size dummy had a negative influence on technical inefficiency. The combined inputs in the group of medium vessels are more efficient than those of small vessels, and the difference was significant at the 10% level of significance. The results suggest that the vessels with a length between 12 and under 15 m are more technically efficient than those with a length between 6 and under 12 m. Because in marine fishing, the use of larger vessels would allow the use of longer gear or stronger engine power in a wider range of conditions, resulting in a higher fishing effort [11]. In addition, marine fish resources in offshore water areas are predicted to be slightly more abundant than the resources in near-shore water areas [5]. The policies of the Vietnamese government showed that medium vessels were licensed to catch in offshore water areas and small vessels were licensed to catch in near-shore water areas [27]. Our data suggested that the mean technical efficiency of the small vessels was 50.0%, whereas the technical efficiency of the medium vessels was 81.9%. The small-scale trawling of the MD could be improved by 50.0% and 18.1% for small and medium vessels, respectively. The result also revealed that the efficiency level of the small vessels was statistically significantly lower than that of the medium vessels ($p < 0.05$). Hence, reducing the small trawl vessels has been a key priority for management due to large technical inefficiencies. Van Nguyen et al. [13] suggested that the less efficient fishers could encourage exit from the fishery by providing feasible livelihood alternatives.

3.3.3. Fishing Gear. Mesh size plays an important role in retaining different species of different sizes, especially the cod-end. The results show that mesh size was positively related to efficiency, but this variable was not significant at the 10% level. Although the coefficient value was relatively small, the use of the mesh size variable minimally affected the efficiency. The vessel's use of a minimal mesh size could bring higher production, but the percentage of trash fish was high. This explanation is that inshore fishing grounds are strongly affected by extremely small mesh sizes because this action could influence the growth stages of fish resources. According to Vietnam's regulation, the cod-end mesh size of trawl vessels operating inshore was 34 mm [37], whereas the fishers used a mesh size of 24.5 mm. In addition, the number of fishing nets also contributed to the revenue. The coefficient of the number of nets on the boat was estimated to have a negative influence on technical inefficiency and was statistically significant at the 1% level. Due to the fact that each net type can effectively catch certain species, fishermen usually bring two to three nets each trip, which allows them to change according to the abundance of each species. In some cases, this can help reduce risks on the sea, such as tearing nets. The net used for fishing has a larger mesh size and was operated at night, while the net used for exploiting shrimp species has a smaller mesh size and was operated during the day.

3.3.4. Fishing Ground. Results show that the small-scale vessels of the MD on the west coast were generally more efficient than those on the east coast. The engine power and the number of fishing days at sea of the west coast vessels were more disparate than those of the east coast vessels. The results of the analysis indicate that the engine power of west coast vessels was approximately 80 HP and the average time spent per trip was around 4 days, whereas the parameters for east coast vessels were 46 HP and 3 days, respectively. The average yield per trip of west coast vessels was also higher (760 kg/trip) than that of east coast vessels (400 kg/trip). Another factor is the distance of the fishing grounds from the harbor. This factor had a positive effect on technical efficiency. It is explained that fishing grounds with a near-shore area are more technically inefficient because fish are scarce and small in size inshore. FAO [5] has shown the relationship between technical efficiency and distance factors; marine fish resources in the coastal waters have already been overexploited.

3.3.5. Cooperation and Information. In the MD, approximately 74-75% of fishermen joined a fishing group, which primarily cooperated on fishing issues. Initially, the fishermen joined a fishing group of 3 to 5 vessels for problem-solving at sea, such as fishing rescue and food exchange. Another form of cooperation was a linkage between fishermen and collectors or wholesalers. The collectors or wholesalers support the fishermen with inputs such as fuel and ice, and in turn, the fishermen have to sell their products to the collectors or wholesalers. The estimated results show that vessels with cooperation were more efficient than those without cooperation. In addition, about 16.6% of the trawl vessels operated without registration. Because the small trawl vessels (e.g., vessels ranging from 6 to under 12 m in length) were limited and new registrations for catching in near-shore water areas were inefficient, they were exchanged [27]. The estimated results show that fishermen who had gear registration in fishing were more efficient than others, and the coefficient was statistically significant at the 10% level. Therefore, the government of Vietnam has implemented several training courses to improve awareness of the protection of fish resources among fishermen, thus improving efficiency and increasing incomes. Small-scale trawling needs to be reorganized due to the over-exploitation of inshore fisheries resources [38].

4. Conclusions

In this study, the average inputs and outputs per trip, as well as vessel- and operator-specific variables, were examined by estimating a translog stochastic production frontier and including a model for relevant vessel- and operator-specific technical inefficiencies. There are substantial differences in efficiency among the trawlers in the sample data. The average technical efficiency for small-scale trawl fishers of the MD was approximately 68.8%. Vessel- and operator-specific variables had a statistically significant impact on the technical efficiency, including the experience of the captains, vessel size, the number of nets on the boat, the fishing ground, distance to the fishing ground, registration of fishing gear, and cooperation in fisheries. Fishermen can potentially improve performance in small-scale trawl vessels, as the ratio of vessels with over 80% technical efficiency makes up 41.3% of the total sample vessels in the study, focusing on the medium vessels. There are several policies for small-scale fisheries, as follows:

(i) Fisheries managers and policymakers need to pay particular attention to who is linking, especially the consumption of output. By encouraging cooperation in inputs, the actors in fisheries should share or supply information together. In addition, each fishing group had one leader who connected with the traders. The vehicles for transporting fish caught from the sea to landings also should be upgraded. For this reason, the quality of fish caught could be stable after landings.

(ii) Fishermen should invest in newer technologies and improve the design as well as cooperation in fishing. If the fishermen have good conditions for their vessels, e.g., newer or larger ones, the efficiency of offshore fisheries will improve. The shift to large-scale fishing has been suitable for the fishing sector's development policy to encourage offshore fishing.

(iii) Fishermen can improve their fishing ability and catch more efficiently by taking several policy measures, such as organizing educational programs, exchanging knowledge among fishermen, and adopting innovations.

Although the study revealed some technical efficiency aspects of trawl fishing in the Mekong Delta, it has some limitations, including data being verbally reported as averages (as opposed to systematically weighted trip-level quantities) and the wide range of vessel sizes even within the small-vessel category.

Data Availability

The data supporting the findings of this study are available from the corresponding authors upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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