Technical Efficiency of Gillnet Fishery in Da Nang, Vietnam:
Application of stochastic production frontier

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This paper presents the result of a study which investigated the technical efficiency of gillnet fishing vessels in Da Nang, Vietnam in 2009 using a stochastic production frontier, which involved the simultaneous estimation of a translog stochastic frontier model and a model for vessel-specific technical inefficiencies. Other important determinants of gillnet fishing fleet were also examined such as output elasticities, returns to scale and marginal productivities of inputs. An inefficiency model was subsequently developed to determine the relevant vessel- and operator-specific factors that could affect the technical efficiency of gillnet fishery. Given the estimated stochastic production frontier model, the ability to determine the potential factors that affect the efficiency and the production process could be investigated. The estimated marginal productivities of inputs for gillnet fishery production could provide some useful insights for fishery managers in formulating management and regulatory policies, and for the gillnet vessel operators in increasing their variable costs and/or employing longer gillnets as well as increasing their benefits by taking onboard more crew members.

Most fisheries worldwide are still open-access resources and managed through input control system (Pascoe and Mardle, 2003). One of the essential approaches for effective fisheries management under such system is to adopt technical efficiency measurements in fisheries. However, research studies that investigate the technical efficiency in commercial fisheries are limited because of inadequate data and few choices of analytical methods (Comitini and Huang, 1967; Noetzel and Norton, 1969; Hannesson, 1983). The fisheries industry in Vietnam is a key sector for the country's economic development, where management is mostly imposed through a series of input control systems such as gear restrictions, minimum mesh size, engine power, fishing licenses, among others. Nevertheless in practice, such controls have not been fully assessed and examined (Son, 2003; Truong and Dap, 2006). A few recent studies attempted to measure the economic performance of certain types of fishing vessels such as the longliners, gillnetters, and purse seiners (Kim Anh *et al*., 2006; Long *et al*., 2008; Luong, 2009), but such studies only covered some aspects on fishing efficiencies associated with costs and earnings of the fleets operating in Nha Trang, Vietnam due to inadequate data and time constraints. The socio-economic information about such fisheries that could be useful for fishery managers in formulating appropriate regulations and policies had not been examined. In recent years, an increasing number of research studies had been conducted in Vietnam assessing the technical efficiency in some economic sectors using the production frontier function approaches (Minh, 2005; Song, 2006; Nhut, 2006; Den *et al*., 2007) but the application of such approaches in the fisheries sector of Vietnam is very limited. Ngoc *et al.* (2009) carried out the only single study on small-scale trawl fisheries in Nha Trang using production frontier approaches. The limited number of such studies in the fisheries sector could be due to the country's fishery management system which is not normally concerned with the economic performance of fishers, as most research studies had been tendentiously directed to the biological aspects of fish stocks such as stock structure, age-specific growth and mortality rates (Van Zwieten *et al*., 2002). Nonetheless, the efficient utilization of the related resources (*e.g.* labor, capital) and sustainable management of the marine resources should be addressed in order to assess the social benefits from marine capture fisheries. Furthermore, the limited frontier studies in marine fisheries can be partly attributed to the lack of data and the complexity of small-scale fisheries in the Southeast Asian region. Therefore, the estimation of stochastic production frontier in the gillnet fishery could provide interesting information for both researchers and managers, and could be useful (as reliable basis) for fishery managers and decision makers not only in Vietnam but also for the other Southeast Asian countries, particularly in formulating appropriate and crucial fishery management regulations.

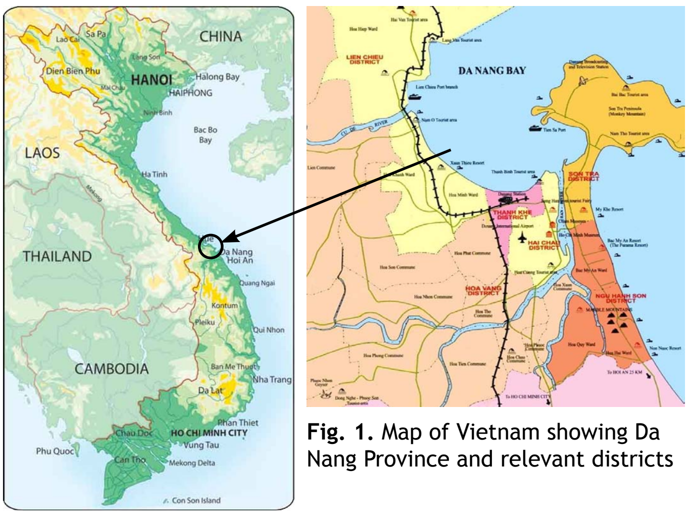

Fig. 1. Map of Vietnam showing Da Nang Province and relevant districts

Gillnet Fishery in Da Nang, Vietnam

Gillnet fishery mainly catching mackerel and tuna, has been in existence in Da Nang since the early 1970s and has been playing an important role in the fisheries sector of Vietnam. This fishery started to develop along with the offshore fishing program initiated by the Government of Vietnam in the mid 1990s. At present, gillnet fishing vessels in Da Nang are mainly found in Son Tra and Thanh Khe Districts with few gillnetters located in Hai Chau and Lien Chieu Districts (**Fig. 1**).

In 2009, Da Nang had a total of 1,932 fishing vessels with 119 (6.2%) gillnetters having engine capacities that range from 22 to 520 Hp and an average of 116.67 Hp but the total engine capacity of the fleet in the Province was about 13,884 Hp (18.0% of the country's total). The average length of the vessels was about 17.28 m (ranging from 8.80 to 21.40 m). Compared with the gillnet fleet in Khanh Hoa Province which had an average engine capacity of 85.60 Hp and average length of 14.10 m (Kim Anh *et al.*, 2006), it appears that the sizes of the gillnet vessels in Da Nang are relatively larger, which could also imply that the investments in gillnet fishery in Da Nang could be higher compared with that of Khanh Hoa's.

In 2009, 98 gillnetters (82.4%) from Da Nang aiming for high fishing efficiency, were organized into gillnet groups with about 22 vessels in each group. The fish catch landed by the gillnet groups during that same year was over 9 million metric tons accounting for around 85.0% of the total fish production of the Province. Each gillnet fishing group comprising about 3-5 vessels were operated collaboratively based on family loyalty, which is known to have brought more benefits to the group members, while the members support each other in terms of sharing information on fishing grounds, providing mechanical support in case of an engine failure, and sharing supplies such as fuel, water and food, among others.

Gillnet fishing vessel in Da Nang, Vietnam

Above: Catch landed by gillnetters in Da Nang
Left: Gulf of Tonkin as the main fishing grounds of gillnetters.

A typical gillnet vessel in Da Nang has a hull length longer than 19 m (for large vessels) and capable of making trips longer than two weeks including travel time. The vessel is usually equipped with 300-350 gillnet sheets per boat (50 m long per sheet) and manned by a captain and crew of 10-11 members. The gillnet vessels in the medium category (17-19 m) normally carry 200-280 sheets, manned by a captain and crew of 8-9 members and making trips that last for 7-10 days. The gillnet vessel in the small category (<17 m) have 150-200 sheets, a captain and crew of 6-7 members and make trips for 4-7 days. Sharing of the benefits from this fishery is based on the monthly net income, which is the difference between the gross revenue and total variable costs except labor costs. The net income is divided into 10.5 parts, where the vessel's owner takes 3.5 parts, 3.0 parts for the fishing gears (shared between the owner and crew members who contributed the gillnet sheets), and the remaining 4.0 parts shared among the laborers.

Gillnet fishing activities take place from the southeast of the Paracel Islands going all the way to the Gulf of Tonkin. The main fishing season is from December to March (April) known as the northeast monsoon, when most gillnet vessels (including the medium and large sizes) operate in the Gulf of Tonkin with mackerel as the main target species comprising about 50-60% of the total catch. During the southwest monsoon (a sub-season) from May (April) to August

(September), many gillnetters operate in the southeast of the Paracel Islands to catch mostly tuna species, constituting about 60-70% of the fish catch. In practice, however, the skippers could identify the appropriate fishing grounds based on the main target species that could be exploited without due consideration of the particular seasons.

The Stochastic Frontier Model

Following Färe *et al.* (1985, 1994), the determinants of the technical efficiency could be determined by applying various methods, which could be either non-parametric such as the Data Envelopment Analysis (DEA) or parametric such as the Stochastic Production Frontier (SPF) analysis. Since the DEA introduced by Charnes *et al.* (1978) is based on mathematical program approach it does not impose any assumptions about functional forms and does not take into account random error, and thus could be biased under the production process that largely involved stochastic elements. In contrast, the SPF approach imposes explicit functional form and distribution assumption on the data and thus, could account for the random errors including those induced by weather and luck (Aigner *et al*., 1976; Aigner *et al.*, 1977; Meeusen and van den Broeck, 1977). The SPF analysis could therefore be appropriate for examining the relative technical efficiency of any "firm" or "entity" that exploits renewable resources due to the involvement of stochastic characteristics in the production process (Kirkley *et al.*, 1995; Sharma and Leung, 1999).

Fishing port in Da Nang, Vietnam

Since fishing activities are largely characterized by many uncertainties, especially in the case of small-scale fisheries, the SPF approach could be used to examine the technical efficiency of fishing vessels as demonstrated in this case study. The general stochastic production frontier model is shown in **Box 1**.

Data Analysis

This study made use of the results of the cross-sectional survey of sample gillnet vessels obtained through the fisher's logbook conducted in 2009 and from the interviews. From a total of 119 registered gillnet vessels operating in 2009 in Da Nang, only 56 gillnetters were randomly selected. The owners and/or captains (skippers) of the selected vessels

Table 1. Variables in the stochastic production frontier and technical inefficiency models for gillnet fishery in Da Nang in 2009

Variable	Mean	S.D.	Min.	Max.
No. of operating months (in months)	10.20	0.80	8.00	12.00
Average annual revenue	868.10	237.20	275.70	1,379.30
Average income per month	47.30	15.40	5.80	79.70
Output				
Gross revenue	84.70	21.60	27.60	125.80
Inputs				
Variable costs (O)	37.30	10.00	19.70	65.70
Crew size in persons (C)	9.90	0.90	8.00	12.00
Length gillnet sheets (N)	294.00	32.00	200.00	360.00
Vessel - and operator - specific variables				
Vessel size dummy ($D_{mediumvessel}$): Medium (0 or 1)	0.58	0.50	0	1.00
Vessel size dummy ($D_{largevessel}$): Large (0 or 1)	0.28	0.45	0	1.00
Engine power (Hp)	140.20	86.9	37.00	360.00
Vessel age (years)	5.50	3.70	1.50	16.00
Net-contributor (persons)	6.10	2.30	1.00	11.00
Skipper's experience (years)	16.60	9.90	2.00	38.00
Education dummy ($D_{education}$): Secondary level (0 or 1)	0.26	0.44	0	1.00
Owner-operated dummy ($D_{owner-operated}$) (0 or 1)	0.50	0.51	0	1.00

Note: Total number of observations n=50. All economic values are in million VND (US$1 = 16,900 VND in 2009). Medium vessel: 17-19 m, Large vessel: >19 m. Crew includes captain *(Source: survey in 2009)*

Box 1. The stochastic production frontier model

$$\ln q_i = \beta \ln x_i + v_i - u_i \quad (1)$$

where q_i is the output produced by firm i, x_i is a vector of factor inputs of the ith firm, and β is a vector of the estimated parameters. The term v_i is a random variable that accounts for the random effects (beyond the control of the firms), which is assumed to be independent and identically distributed (iid)N$(0,\sigma_v^2)$, independent of u_i, and can be positive or negative. The term u_i is a non-negative random variable which accounts for pure technical inefficiency in production and is assumed to be independently and identically distributed and with truncations (at zero) of the normal distribution (Aigner *et al.*, 1977) with mean, u_i- that measures the technical inefficiency relative to the frontier and describes the distance of firm ith from the frontier output (Coelli *et al.*, 1998), and variance, $\sigma_u^2(|N(\mu_i,\sigma_u^2|)$. The assumption of the independent distribution between u_i and v_i allows the separation of the stochastic (statistical noise) and inefficiency effects in the model (Bauer, 1990). This is considered as one of the advantages of assessing the technical efficiency using the SPF model.

The method of the maximum likelihood used to estimate the parameters of the stochastic frontier in equation (**1**). The parameters estimated include β and variance parameters such as $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2/\sigma^2$ (Battese and Corra, 1977). Where, σ^2 is the sum of the error variance, while γ measures the total variation of output from the frontier attributed to the existence of random noise or inefficiency. Note that the value of γ lies between zero and one. The inefficiency is not present when $\gamma=0$ which means that all deviations from the frontier are entirely due to random noise, and if $\gamma=1$ then the deviation is completely caused by inefficiency effects (Battese and Coelli, 1995).

Based on the Battese and Coelli (1995) model, the random variable associated with technical inefficiency, u_i, was further assumed as a function of various operator- and vessel-specific variables that are hypothesized to influence the technical inefficiencies, as shown in equation (**2**):

$$u_i = z_i\delta + w_i \quad (2)$$

where z_i is a vector of explanatory variables associated with the technical inefficiency of production of the ith firm, δ is an unknown vector of coefficients that is to be estimated, and w_i is a (iid) random error term, which is defined by the truncation of the normal distribution with zero mean and variance, σ_u^2, such that the point of truncation is $-z_i\delta$, *i.e.*, $w_i \geq -z_i\delta$. These assumptions are consistent with u_i being a non-negative truncation of the $N(z_i\delta, \sigma_u^2)$-distribution.

It should be noted that both the frontier model in equation (**1**) and the inefficiency model in equation (**2**) could include intercept parameters if the inefficiency effects are stochastic and have particular distributional properties (Coelli and Battese, 1996). Moreover, the stochastic frontier requires a priori functional form specification. This means that it is necessary to impose restrictions on the model. By doing so, these restrictions could be tested by using the following generalized likelihood ratio (LR):

$$LR = -2\{\ln[L(H_0)] - \ln[L(H_1)]\} \quad (3)$$

where $\ln[L(H_0)]$ and $\ln[L(H_1)]$ are the values of the log-likelihood function under the null (H_0) and alternative (H_1) hypotheses, respectively. The restrictions form the basis of the null hypothesis, while the unrestricted model being used for the alternative hypothesis. LR has a Chi-square (χ^2) distribution with the number of degrees of freedom provided by the number of restrictions imposed.

In order to test the specification of the models, a number of trials have been proposed with the standard test being the one-sided generalized likelihood ratio-test for the existence of a frontier (the presence of technical inefficiency), *i.e.* H_0: $\gamma=0$. This test has an asymptotic distribution ($0<\gamma<1$) and the critical values of the test are obtained from Kodde and Palm (1986). The other key test is the correct functional form of the stochastic production frontier (equation (**1**)) which is the Cobb-Douglas form (*i.e.* H_0: $\beta_{i,k} = 0$, where k denotes the kth input variable). This null hypothesis is tested against the alternative hypothesis that the translog is the most appropriate functional form (*i.e.* H_1: $\beta_{i,k} \neq 0$). Further, the appropriate assumption for the inefficiency distribution as a truncated normal curve can also be tested under the null hypothesis so that all the parameters of the technical inefficiency model are considered, except the intercept at zero.

Based on the model estimations, the output for each firm could be compared with the frontier level of output that is known as the best output given the level of inputs employed, and this deviation indicates the level of inefficiency of the firm. Therefore, the technical efficiency score for the ith firm in the sample (TE_i) under the given equations (**1**) and (**2**) that would be defined as the ratio of observed output to the corresponding best output, is given by (Coelli *et al.*, 2005) as:

$$TE_i = \frac{q_i}{\exp(\beta \ln x + v_i)} = \frac{\exp(\beta \ln x + v_i - u_i)}{\exp(\beta \ln x + v_i)} = \exp(-u_i) = \exp(-z_i\delta - w_i) \quad (4)$$

where TE_i is the relative technical efficiency of the firm ($0<TE<1$). Note that, when $u_i=0$ then the ith firm lies on the stochastic frontier and is known as technically efficient. If $u_i>0$, the firm i lies below the frontier, which means that the firm is inefficient. The elasticity of output with respect to the kth input variable (ε_k), which measures the responsiveness of the output to a 1% change in the kth input, could be evaluated as the mean values of the relevant data points and can be derived from:

$$\varepsilon_k = \frac{\partial \ln q}{\partial \ln x_k} = \beta_k + 2\beta_{kk}\ln x_k + \sum_j \beta_{kj}\ln x_j \quad (5)$$

where β_k is the coefficient on the x_k term, β_{kk} is the coefficient on the $\ln^2 x_k$ term and β_{kj} is the coefficient of the cross product of x_k and x_j, where both k and j are inputs.
The measure for returns to scale (RTS), representing the percentage change in output due to a proportional change in the use of all inputs, is estimated as the sum of output elasticities for all inputs (Chambers, 1989). The measurement of the marginal product of the kth input at mean values of the output and relevant input variables is calculated as:

$$\frac{\partial q}{\partial x_k} = \varepsilon_k \frac{\bar{q}}{\bar{x}_k} \quad (6)$$

were interviewed from January to February of 2010 using a questionnaire which aimed to collect information on various aspects of gillnet fishery, including vessel and fishing gear characteristics, fishing grounds, target species, crew size, and the net contribution of crew members.

The personal data of the skippers such as age, years of fishing experience, educational level, and whether the vessel is owner-operated or not, were also collected through the interview. The number of vessels finally considered in the study was 50, and the data were analyzed for the estimation of the stochastic frontier. The results showed considerable heterogeneity in terms of technical and operational characteristics such as vessel size, age of crew, crew size, variable costs, and the total length of the gillnets, as well as the skipper's age, experience, and educational level (**Table 1**).

Hull lengths for the sample gillnet fleet ranged from 14.8 to 21.0 m with an average length of 18.1 m. The age of gillnet vessels varied from 1.5 to 16.0 years with mean of 5.5 years (also the years of ownership by the present owner). The average crew size was 9.9 persons which ranges from 8.0 to 12.0 persons. The sample gillnets fleet also showed a considerable variation in the variable costs ranging from 19.7 to 65.7 million VND with an average of 37.3 million VND. The number of gillnet sheets used by the sample gillnetters ranged from 200 to 360 sheets with mean of 294 sheets. The average monthly number of days at sea including time spent for traveling is 17.6 days, varying from 11 to 22 days. The age of the skippers also varied from 28 to 60 years old with an average age of 43.1 years. The skippers had relatively high levels of experience in fishing activities at an average of 16.6 years.

As shown in **Table 1**, one of the most important economic performance indicators of the sample gillnet fleet is positive income. The total gross revenue of the vessels substantially varied from 275.7 to 1,379.3 million VND, with an average of 868.1 million VND, compared with the average annual revenue of a gillnetters in Nha Trang City which was 851.3 million VND (Kim Anh *et al.*, 2006), which clearly indicated that the revenue of gillnet vessels operating in Da Nang was relatively higher than the vessels in Nha Trang. Furthermore, the correlation coefficients between the output and potential inputs in the frontier model showed multicollinearity. The partial correlation of the variable costs (*O*) with labor (*C*), and the number of gillnet sheets used per vessel (*N*) are 0.51 and 0.42, respectively, with the correlation of labor and number of gillnet sheets being 0.47.

Empirical Models

In most economic sectors, outputs can be defined as the physical measure of the volume, but in fisheries especially in tropical waters such as in Vietnam, the outputs are characterized by the different species in the catch often receiving different prices in the market. Therefore, in examining the relative technical efficiency of gillnet fishery, revenue is the reasonable measurement of the variable outputs. Furthermore, in using the cross-sectional data from the 2009 survey to analyze the stochastic production frontier function, it was assumed that the prices of the outputs (*i.e.* tuna, mackerel) and all variable inputs used are the same for all vessels.

Recent literatures on production and efficiency in fisheries (Squires and Kirkley, 1999; Grafton *et al.*, 2000) indicated a range of different input measures used, the most common of which are capital, capital utilization, stock size, and labor utilization. However, the exact choice of input variables for modeling differs among the studies as this depended largely on the availability of data, the expectation to capture the full range of inputs employed, and the characteristics of the fishery. Use of inappropriate measures of the inputs could lead to mis-specification of the model, which affects the corresponding efficiency estimation (Campbell, 1991).

With regards to the technical efficiency measurement of the gillnet fishery, Pascoe *et al.* (2001) examined the effects of economic versus physical input measures on the technical efficiency of the Danish gillnet fleets. The physical input measures included the vessel gross tonnage and horse power, with fuel consumption used as key input for both features related to the vessel size (*e.g.* hull length and horse power) as well as capital utilization (*i.e.* fishing days). Squires *et al.* (2003) used a range of different input measures for the analysis of the Malaysian gillnet fishery such as vessel GRT as proxies of the vessel capital stock, the number of crew employed per vessel as a variable input, and the number of trips per month representing variable input usage. In the case of fisheries in Vietnam, Kim Anh *et al.* (2006) used the hull length and the main engine power as proxies of the vessel fishing effort in modeling the gillnet fishery in Nha Trang. The study also used some other variables such as vessel age, numbers of gillnet sheets (or the total gillnet length), and monetary investments in fishing gear and equipment. While Dien (2009) used the number of days at sea and number of crew for the analysis in modeling the gillnet fleets in central Vietnam, the input variables were aggregated into three categories, namely: (1) the variable costs used by each vessel per month including fuel, ice, and other miscellaneous items, known as proxy of the capital utilization rate (Squires, 1987; Sharma and Leung, 1999); (2) the number of crew members

Box 2. Functional form of the technical efficiency model	
$\ln(\text{Revenue}_i) = \beta_0 + \beta_1\ln(O_i) + \beta_2\ln(C_i) + \beta_3\ln(N_i) + \beta_{11}(\ln O_i)2 + \beta_{22}(\ln C_i)2+$ $\beta_{33}(\ln N_i)^2 + \beta_{12}\ln O_i \ln C_i + \beta_{13}\ln O_i \ln N_i + \beta_{23}\ln C_i \ln N_i + v_i - u_i$	(7)
where the output variable is represented in terms of revenue per month in million VND; O denotes the variable costs used by each vessel per month, including fuel, ice, minor repairs, and other miscellaneous items, except labor cost (million VND/month); C is the number of crew onboard the vessel, including the captain (persons); N denotes the number of gillnet sheets used by each vessel (units); and v_i and u_i are error terms as defined in the previous section.	

Box 3. The functional form of the inefficiency model	
$U_i = \delta_0 + \delta_1 D_{mediumvessel} + \delta_2 D_{largevessel} + \delta_3\ln(\text{enginepower}_i) + \delta_4\ln(\text{vesselage}_i)$ $+ \delta_5\ln(\text{netcontributor}_i) + \delta_6\ln(\text{experience}_i) + \delta_7 D_{education} + \delta_8 D_{owner\text{-}operated} + w_i$	(8)
where Ds denotes the dummy variables and w_i is the random error term as defined in the previous section.	

Table 2. Generalized likelihood ratio tests of the hypotheses for parameters of the stochastic production frontier and technical inefficiency models for the gillnet fishery in Da Nang

Null hypothesis	Log-likelihood value	Number of restrictions	Critical value (χ^2)
$H_0 : \gamma = \delta_0 = \delta_1 = \ldots = \delta_8 = 0$	35.202	10	22.525 *
$H_0 : \beta_{11} = \beta_{22} = \beta_{33} = \beta_{12} = \beta_{13} = \beta_{23} = 0$	13.560	6	12.590 **
$H_0 : \delta_1 = \delta_2 = \ldots = \delta_8 = 0$	35.610	8	15.500 **

Note: *, ** are statistically significant at 1% and 5% levels, respectively. The correct critical values for the first hypothesis is obtained from Table 1 of Kodde and Palm (1986, p. 1,246)

onboard the vessel including the captain considered as key variable input generating fishing effort and impacting on the level of gillnet fishing efficiencies since more crew may allow the removal and processing of the catch more quickly and in turn, allows for more time for fishing; and (3) the number of gillnet sheets as the main physical input - as proxy for investment in the level of capital employed. There are several potential functional forms that 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 (Kirkley *et al*., 1995). The appropriateness of the translog functional form of the model was tested against a Cobb-Douglas specification. The functional form of the technical efficiency model is indicated in **Box 2.**

For the inefficiency model, a number of relevant vessel- and owner-specific variables were hypothesized to influence the technical efficiency for the gillnet vessel, such as: (1) vessel size dummy (value 1 for medium size vessel, 0 otherwise); (2) vessel size dummy (value 1 for large size vessel, 0 otherwise); (3) vessel's engine in Hp; (4) vessel age in years (ownership of vessel by present owner) representing vessel characteristics; (5) number of crew members who contribute gillnet sheets (total net sheets) used by each vessel; (6) skipper's experience (years); (7) level of formal education dummy (value 1 if operator finished secondary school, 0 for skippers with lower educational level (note: no skippers had a high school education in the data set)); and (8) whether or not the vessel is owner-operated, which may closely relate to fishery management and performance, also examined as a dummy variable (value 1 if vessel was owner-operated, 0 otherwise). The functional form of the inefficiency model is shown in **Box 3**.

Empirical Results

The parameters of the stochastic production frontier model using equation (1), and those for the technical inefficiency model using equation (2), were estimated simultaneously by using the maximum-likelihood estimation (MLE) program Frontier 4.1 (Coelli, 1994). The generalized likelihood ratio tests of the key null hypotheses involving the restrictions on the parameters to be estimated involved the β-coefficients and variance parameter γ, in the stochastic production frontier and the δ-coefficients in the technical inefficiency model, as presented in **Table 2**.

The first null hypothesis test showed that the effects of the technical inefficiency are not present in the model, $\gamma = \delta_0 = \delta_1 = \ldots = \delta_8 = 0$. The likelihood-ratio (LR) test statistic is asymptotically distributed as a mixture of Chi-square distributions, and such test statistic exceeds the 1% critical value $\chi^2_{0.99}(10) = 22.525$, which is taken from Table 1 of Kodde and Palm (1986). Thus, the LR test led to the rejection of the null hypothesis that no technical inefficiency exists in the stochastic production frontier (at the significant

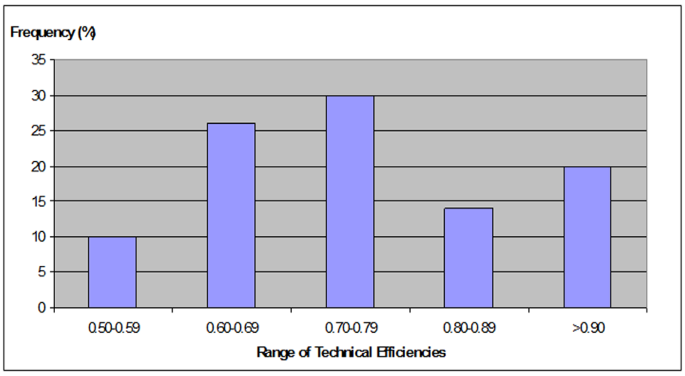

Fig. 2. Frequency distribution of technical efficiencies for the gillnet fishery in Da Nang, Vietnam

level of 5% or less), and also implied that the traditional average of the ordinary least square (OLS) function is not suitable for this study. The second null hypothesis indicated that the correct functional form of the model is Cobb-Douglas, imposed by removing the squared and cross product terms from the translog production function, which was rejected at 5% level of significance. Thus, the LR tests suggested that the translog is the most appropriate functional form for the analysis of gillnet vessels in this study (the estimated models were well specified). Finally, the hypothesis that the technical inefficiency effects have the same truncated-normal distribution with a mean equal to δ_0, given by all the parameters of the technical inefficiency model except the intercept at zero, was also rejected (at 5% level of significance).

Technical Efficiencies

The technical efficiency scores for the Da Nang-based gillnet vessels ranged from 0.55 to 0.98, with mean efficiency level of 0.76, substantially lower than 0.84 and 0.88 for the Malaysian gillnet artisanal fishery in the East and West coasts of Malaysia, respectively (Squires *et al.*, 2003). This result indicates that the means of the individual technical scores for the Da Nang-based gillnet fleets are consistent with those generally found from stochastic frontiers for agriculture in developing countries (Ali and Byerlee, 1991; Bravo-Ureta and Pinheiro, 1993).

The frequency distribution of the estimated technical efficiency scores relative to the best practice frontier scores is illustrated in **Fig. 2**. Majority of the vessels have a technical efficiency score of 0.70 to 0.79 (30%), followed by 26% of vessels with efficiency scores of 0.60-0.69. While the least proportion of the observed vessels (10%) had technical efficiency indices of 0.50-0.59. The sample vessels that had technical efficiency index of 0.90 or above accounted for just 20% and vessels with efficiency indices of 0.80-0.89 accounted for 14%.

Table 3. Parameter estimates of the stochastic production frontier and technical inefficiency models

	Coefficient	Asymptotic t-ratio	
Stochastic production frontier			
Constant	-106.347	-46.922	***
ln (Variable costs)	0.820	3.520	***
ln (Crew size)	10.210	28.630	***
ln (Net sheets)	33.965	37.509	***
ln (Operating costs)^2	-0.462	-2.444	**
ln (Crew size)^2	-2.514	-14.608	***
ln (Net sheets)^2	-2.680	-15.327	***
ln (Variable costs) x ln (Crew size)	1.862	3.202	***
ln (Variable costs) x ln (Net sheets)	-0.181	-0.326	
ln (Crew size) x ln (Net sheets)	-0.932	-1.387	
Technical inefficiency model			
Constant	0.965	5.092	***
Vessel size dummy: Medium (0 or 1)	-0.028	-0.431	
Vessel size dummy: Large (0 or 1)	-0.016	-0.237	
Engine power (Hp)	-0.093	-2.247	**
Vessel age (years)	0.057	1.882	*
Net-contributor (persons)	-0.254	-6.340	***
Skipper's experience	0.058	2.017	**
Education dummy: Secondary level (0 or 1)	0.026	0.536	
Owner-operated dummy (0 or 1)	-0.055	-1.295	
Variance parameter			
σ^2	**0.011**	5.511	***
γ	**0.780**	12.045	***

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

Since slightly more than 30% of the sample vessels have technical efficiency score of 0.80 or higher, this implies that in 2009 limited number of vessels displayed substantially higher levels of technical efficiency (operating close to the efficient frontier). Notably, however, none of the sampled vessels had a technical efficiency index lower than 0.50. Therefore, majority of the gillnetters have the potential to improve their technical efficiency (productivity) given the state of technologies and conditions of the resources.

Factors Affecting Technical Inefficiencies

Given the specifications of the stochastic production frontier model defined in equations (**1**) and (**2**), the generalized likelihood-ratio tests indicated that the joint effect of the vessel- and operator-specific variables on the technical inefficiencies is highly significant in explaining the variation of the productive performances of the Da Nang-based gillnet vessels. However as shown in **Table 3**, none of the coefficients associated with vessel size, skipper's educational level, and the owner-operator dummies have significant effects on technical efficiency. While the individual effects of the remaining variables (*i.e.* engine power, vessel's age, net-contributor, and skipper's experience) were statistically significant (based on the asymptotic t-ratios).

The value of γ=0.78, which is statistically significant at 1% level, confirmed that the output variability of the gillnet vessels is dominated by technical inefficiency rather than uncontrollable random shocks, and that the skippers have good knowledge of resource abundance, availability and spatial distribution (Kirkley *et al.*, 1995) as well as the willingness of the skippers to take more risks given the nature of fishing (*i.e.* weather, resource and environmental conditions) normally characterized by many uncertainties. Otherwise, the high gamma (γ) value in the model would imply high relative contribution of inefficiency to the total variation, indicating that most of the variation in the output accounting for the potential factors in the production frontier function was attributed to the differences in efficiency rather than in random error or "luck".

The factors affecting technical inefficiency can be explained by the significance of the estimated coefficients in the inefficiency model (equation (**2**)), as illustrated in **Table 3**. A negative sign indicates a decrease in technical inefficiency (implying positive effect or an increase in technical efficiency) and inversely positive sign implies negative effect. Given the estimated technical inefficiencies (**Table 3**), the negative coefficients for the vessel size dummies although not significant, suggested a positive effect of vessel size on technical efficiency. The negative coefficient for engine power means positive influence, while vessel age has negative influence on the technical efficiency of the gillnet fleet. As expected, owner-operated vessels were technically more likely to be efficient than those operated by hired skippers. Similarly, the more gillnet sheet contributors implied more technical efficiency was gained, thus the net-contributed variable had a positive effect on the vessel's technical efficiency. In contrast, the skipper's fishing experience and educational attainment had negative effects on technical efficiency, quite different from previous studies which found that the experience and educational level of the captain had (strong) positive influence on the vessel's efficiency (Kirkley *et al*., 1998; Squires and Kirkley, 1999).

Elasticity and Returns to Scale

Output elasticity is a useful way of characterizing the responsiveness of potential inputs to the changes in the output, since the coefficients of the translog stochastic production frontier (equation (**1**)) could not be interpreted in a straightforward way. Thus, the estimated values of the output elasticities were calculated at the point of the means of relevant data point defined in equation (**5**). The estimates of the output elasticities for the Da Nang gillnet fishery showed that the values for variable expenses, crew size and the amount of gear used was positive (expected finding) and less than 1. The output (revenue) elasticity of the variable costs was highest at 0.72, followed by the total length of the gillnet (0.71), and 0.14 for the labor variable. The estimated output elasticities did not vary with the variations in two input levels related to variable costs and the length of the gillnet net. In contrast, comparing with some earlier studies that also examined the output elasticities in fisheries, the estimated elasticity of gear length from this study was different from the estimation obtained from previous studies.

For example, Kompas *et al*. (2003) found that the length of net sheets had negative effect on the efficiency of Australia's prawn fishery. Similarly, Fousekis and Konaris (2003) also concluded that there was negative influence of the gear used on vessel efficiency in Greece. In such cases, the vessels could have used more gear than the optimal level. Inversely, in the case of Vietnam, the findings of the current study suggested that there is potential for further development of the offshore fishery (increasing fishing efforts) at least in the short run, which is consistent with some reports that the maximum sustainable yield for the offshore EEZ of Vietnam is about 1.1 million mt, but the offshore landing (excluding illegal, unreported and unregulated foreign fishing) was estimated at around 0.6 mt (FAO, 2005).

With regards to the elasticity associated to the number of crew members, the positive estimated value (0.14) is consistent with those from previous studies (Kirkley *et al.*, 1995; Pascoe and Robinson, 1998; Pascoe *et al.*, 2001). However, this estimated value is relatively small and for practical purposes, not an important parameter in the production frontier. This implied that the differences in technical efficiency between vessels resulted in the inconsiderable effect of the labor factor. Since the crew members received a share of the income from the fishing operations, only very few or no attempts to increase the number of crew members onboard the fishing vessels. The returns to scale for the gillnet fishery in Da Nang, computed as the sum of the output elasticities for all inputs was 1.57. The improved production from gillnet fishery can therefore be attributed to the increasing returns to scale based on the 2009 data, a reasonable result for static gear boats such as gillnetters. The empirical findings on increasing returns imply that an expansion of all three inputs (variable costs, labor, and the length of net gear uses) by 10% would increase the output by more than 15%, given constant stock abundance. The estimation of returns to scale for this fishery was consistent with those from previous research studies by Kirkley *et al.* (1995 and 1998), Pascoe and Robinson (1998), Pascoe *et al.*(2001), and Sharma and Leung (1999).

Marginal Productivities of Inputs

The estimated marginal contributions of each input to the gross revenue for the Da Nang gillnet fishery were derived from equation (**6**). The estimated value of the marginal product based on the output variable used in the production frontier analysis, was measured in terms of value instead of quantity. Thus, given the 2009 data on gillnet fishery production, the estimated marginal product of the variable costs, crew size, and the length of gillnet used, were 1.626, 1.223, and 0.204, respectively, showing substantial variation in the marginal productivities among the different inputs used, and suggesting that the contribution of each input to the vessel gross revenue was quite different.

Discussions

Factors Affecting the Efficiency and Fishing Process

As shown in the estimated inefficiency model, the two vessel size dummies for the sample gillnet fleet had positive influence on technical efficiency. Although the influence was not significant as the coefficient values were relatively small, the result indicated that the vessel size variables had minimally affected the efficiency, which could be because in the gillnet fishery, the use of larger vessel would allow the use of more or longer gear (gillnet sheets) in a wider range of conditions, and that the fishing effort of such vessels would be substantially higher, and consequently obtain proportionally higher levels of outputs (Pascoe and Mardle, 2003). Another possible reason could be the greater capacity of larger vessels to operate in remote and offshore fishing grounds having more resources for exploitation even during difficult weather conditions. Moreover, larger vessels are also capable of taking longer fishing trips with sufficient quantities of available provisions, ice, and fuel. However, larger vessels would consume more fuel per hour compared to the smaller ones, and hence could incur higher operational expenses per trip.

One interesting outcome from the inefficiency estimation was the statistically significant positive impact of engine power on vessel efficiency (at 5% confidence level), a quite surprising result because gillnets are considered as static gears, so the engine power of the gillnetters could not define the key factor influencing the level of fishing efficiencies compared with vessels operating mobile fishing gears (*i.e.* trawlers). The two rational explanations from such result could be: (1) greater engine power could extend the carrying capacity and allows more hauls to be done over a given period of time; and (2) with higher horse power the vessels could move faster between fishing grounds, reducing the time for traveling and consequently the cost of fuel consumed. Furthermore, the age of the vessel had negative effect on technical efficiency which was statistically significant at 10% level, consistent with the suggestion of Kim Anh *et al.* (2006) that the age of a vessel also affected the Khanh Hoa gillnet fishing vessel revenues. This is because older vessels could have encounter trouble due to the possible dilapidation of the materials used in constructing the vessel, hull design, size, winch equipment or engine. In addition, older vessels would require more frequent repairs and regular maintenance, and although their operating time may be reduced higher cost of operational expenses could be incurred. Therefore, as the age of a vessel increases, its efficiency decreases.

The estimated technical inefficiencies for the Da Nang-based gillnet vessels also showed that the vessel gross revenue increases with the number of net-contributors of the gillnet sheets used. The positive influence was statistically significant at 5% level or better, and could be explained from the efforts of the fishers who work harder for the vessel's operation as they have more responsibilities for their own benefit. This is considering the share of the benefits which are distributed to the members who have invested in equipping the vessel with the fishing gear commensurate with the amount of gear contributed and used in the fishing operations, thus significantly improving their earnings. Moreover, the labor force could be more stable during the fishing operations because as net-contributors they have to work onboard as part of the labor force contracted by the vessel owner. This characteristic is an important factor for the gillnet fishery since gillnetters usually require a minimum number of crew of at least seven members for each fishing operation. Some fishers have in fact left their current vessel owner to find jobs in new vessels, especially after finding out that some of their fishing trips had been less profitable, an inevitable practice since fishers need to find other opportunities that could provide sufficient financial support for their families as the main income of most fishers' families had been derived from fishing activities.

From the analysis of the inefficiency model, the positive sign for the fishing experience and formal education of the vessels' captains or skippers was contrary to expectations suggesting that an increase in the values of such variables could decrease the efficiency. In reality, the fishing experience of the vessel captains usually provides better information on locating the fishing grounds, weather patterns, current and tidal conditions, and the areas where the target species could be abundant. Thus, it should be recognized that the technical inefficiency of a vessel may be reduced by improving the literacy and cognitive skills of captains that enable them to adopt modern technical innovations. The estimated value of γ=0.78 suggested that the differences in technical efficiency across individual vessels are predominantly attributed to technical inefficiencies rather than to random effects.

Questions could arise as to the main determinants of vessel production without considering the effect of the skippers' skills (*i.e.* years of fishing experience and educational level), and as to why the offshore fishing program of Vietnam had been less effective. This could be explained from the insufficient information on offshore resources, inadequate understanding of the economic realities of offshore fleets, and unsuitability of technologies onboard fishing vessels. However, the positive estimated coefficients of the skippers' experience and educational level could be explained by the characteristics of gillnet fisheries being risky due to uncertainties especially in remote fishing grounds, severe weather conditions, and the variability of fishing targets which are highly migratory species (*i.e.* tuna, mackerel, swordfish). This implies that younger skippers with less experience or lower educational level could be more efficient than those who obtained more years experience in fishing or better educational attainment, as younger skippers are often more willing to change their fishing patterns in order to succeed and are always ready to cope with the difficulties or take more risks. Thus, the effects of longer experience or higher formal educational level of the captains on a vessel's efficiency, appears uncertain in this study. Moreover, fisheries in Vietnam like in many developing countries, is generally characterized by being small-scale, and the development of technologies seems constrained by such condition. Therefore, the cognitive skills required of the captains to adopt new technologies in fisheries may not play an important role in the developing countries compared with those in the developed fisheries. Another possible reason could be related to the reliability of the data collected as information on the socio-economic factors of fishers are normally difficult to obtain.

Another interesting result from this study is the positive effect of both owning and operating a vessel on the vessel's efficiency suggesting that owner-operated vessels tend to be more efficient than those operated by none-owner captains. This is consistent with that of previous research studies which suggested that incentives affect the level of technical efficiency. However, the owner-operator dummy variable was insignificant in explaining the differences of the technical inefficiency for the Da Nang gillnet fishery, which could be due to the fact that vessel owners may have good relationship with their hired captains who normally are their relatives. Thus, the vessel owners could increase the rate of return by recruiting their relatives to work as captains or by operating the vessels themselves.

In the frontier model, most of the coefficients estimated for the parameters were significant suggesting their significant influence on the production process. The positive coefficients of variable costs, crew size, and the length of the gillnet sheets, and the negative coefficients of their squared terms imply that the relationship between the vessel's gross revenue and the variable inputs is hump shaped (normal distribution). Thus, the vessel's gross revenue increases with variable costs, crew size, and the total length of the gillnet sheet, although at a decreasing rate. The output elasticities of the variable costs, labor and the total length of the net sheets were estimated at 0.72, 0.14 and 0.71, respectively (using equation (**5**)). The elasticity value less than 1.0 indicates that the output (revenue) is less sensitive to changes in the level of input or is 'inelastic'. In such a case, a one per cent increase in the level of inputs would lead to less than one percent increase in the level of outputs.

Therefore, a 10% increase in variable expenses, crew, and the length of net sheet used would lead to increase in the vessel's gross revenue by 7.20%, 1.40%, and 7.10%, respectively. The marginal production from gillnet fishery suggested that overall, fishers could increase their per-month gross revenue by more than 1.6 million VND by adding a variable cost of over 1.2 million VND for every crew member added. Similarly, an average gross revenue per month of gillnet fishery in Da Nang could be increased by more than 0.2 million VND by using longer gillnet sheets.

Technical Efficiency Relative to Input Use and Economic Performance

Technical efficiency and factor utilization

As shown in **Table 4**, vessels with mean technical efficiency lower than 0.89 than the higher technical efficiency, were those that had higher variable costs. The distribution of technical efficiency of the 28 (56%) gillnet vessels with estimated efficiency ranging from 0.60 to 0.79 had average variable costs ranging from 34.598 million VND to 37.342 million VND per month per vessel, while the operating expenses incurred by the 7 vessels with estimated technical efficiency was between 0.80 and 0.89 million VND. The 5 vessels with the lowest efficiency of 0.50 to 0.59 had the smallest variable costs at an average of 28.616 million VND. However, the mean technical efficiency of the 10 vessels that incurred the lower costs (41.268 million VND) was higher than 0.90 compared with those vessels with technical efficiency lower than 0.89 (between 0.80 and 0.89), which incurred higher costs (43.051 million VND).

This could be brought about by the number of days at sea, since some vessels could improve their performance by increasing the number of fishing days or by operating in a wider range of areas and uncertain conditions (*e.g.* fishing in remote fishing grounds), particularly during the main fishing season. Thus, the total costs incurred by these vessels would increase along with the number of days spent in fishing as more provisions, ice, and fuel would be used. However, some gillnet vessels could not spend more days at sea due to

Table 4. Average technical efficiency, input use, and economic performance, 2009

Efficiency	Variable Costs	Crew size	Net Length	Gross Revenue	Total Income	Average crew share
0.90-0.99 [10]	41.268	10.10	305.00	106.630	65.360	2.706
0.80-0.89 [7]	43.051	10.00	314.29	104.414	61.360	2.338
0.70-0.79 [15]	37.342	10.00	290.00	84.787	47.440	1.807
0.60-0.69 [13]	34.598	9.77	291.54	69.328	34.730	1.265
0.50-0.59 [5]	28.616	9.20	262.00	52.484	23.870	0.988

Note: All economic values are in million VND (US$1 = 16,900 VND); Crew size is the number of crew members; Net length is the number of net sheets used; Average crew shares denote the earnings per crew member per month. All measurements, except number of net sheets and crew size, are on per-month basis. Numbers in brackets indicate the number of observations.

their capacity in terms of vessel size and available onboard technologies. Furthermore, as the landings are unprocessed fish with simple catch preservation techniques used (catch is kept on ice), so the quality of fish catch could be reduced and in turn, receive lower price (earnings) if a vessel would take very long period per fishing trip.

The technical efficiency value for crew size was high at 0.80-0.89 for some vessels but lower at 0.70-0.79 for some although the vessels used the same number of crew that averaged at 10.00 persons per vessel. Vessels with the highest technical efficiency score (>0.90) used more labor with an average of 10.10 persons, while the technical efficiency levels were lowest for vessels with the least crew size at an average of 9.77 persons and 9.20 persons at 0.60 to 0.69 and 0.50 to 0.59, respectively. However, the trend of the relationship between technical efficiency and the level of crew size may not be very evident from the result of this study, and could not be reliable for policy implication purposes.

Technical efficiency and physical fixed inputs

The effects of the length of the gillnet sheets used on vessel efficiency (**Table 4**), were found similar with the impacts of the operating costs. In general, higher technical efficiency was found for gillnet vessels having longer gillnet sheets used with mean efficiency level lower than 0.89. The lowest efficiency range of 0.50-0.59 was found for vessels using the shortest average length of the net sheets (262.00 sheets). While the technical efficiency levels ranged from 0.80 to 0.89 for vessels which used maximum length of net sheets with an average length of about 15,714 meters (314.29 sheets), which could be due to the fact that in gillnet fisheries, the length of the net is the main physical fixed input representing the operational characteristics and generating the fishing effort. Thus, the vessel's efficiency could be increased by expanding the level of fishing effort (longer gillnet sheets) without taking into consideration the available fish stocks, consistent with Kim Anh *et al.* (2006) in the case of gillnet fishery in Khanh Hoa Province. In reality however, the vessels also could not always fish with a very long gillnet sheets as this would depend on the labor force available, the fishing process as time is limited, and other vessel characteristics. Thus, some gillnet vessels had high technical efficiency (above 0.90) even with slightly shorter gillnet length (15,250 meters or 305.00 sheets).

Technical efficiency and economic performance

Table 4 also shows that the estimated technical efficiency of the vessels could be compared with its economic performance as in the case of the sample gillnet fleet operating in Da Nang in 2009. The results showed that the average monthly income of the gillnet vessels varied from 23.870 million VND to 65.360 million VND with an average of 46.552 million VND. The average crew share per month per member per vessel also varied greatly from 0.988 million VND to 2.706 million VND with mean of 1.821 million VND, but higher than the average monthly share of a crew of longliners at 1.700 million VND (Long *et al.*, 2006). This implies that the owner and crew of an average gillnetter is not only capable of covering all the total operating expenses, but also have significant net returns for each month of fishing operation.

Thus, vessels with higher average technical efficiency per month also had higher average total income obtained after deducting the total variable costs per month per vessel, and had higher average share per crew member per month as well. The 10 vessels of the sample gillnet fishery with estimated technical efficiency between 0.90-0.99 had the highest average total income per vessel per month (65.360 million VND) and subsequently had the highest average share per crew member per month (2.706 million VND). While the average income and crew's share of the 5 vessels with the lowest estimated efficiency range of 0.50-0.59, were only 23.870 million VND per month per vessel and 0.988 million VND per month per member, respectively.

Policy Implications

Based on the result of the production frontier analysis for the sample gillnet vessels, majority have the potentials for improving their performance efficiency, although some vessels were found to be highly efficient operating closely to the efficient frontier. In theory, the sample vessels on the average could have increased their 2009 per-month gross revenue of about more than 32% by operating at full technical efficiency, which is possible in the short-term and can be attained by increasing the level of their fishing efforts (*i.e.* employing longer gillnet sheets). However in the long-term, productivity gains may not be achieved since increased fishing effort would have negative influence on the resource stocks for the gillnet fisheries.

From a different perspective, fishers usually have little control over the prices of their catch since the middlemen normally control the output prices instead. Otherwise, the vessel's revenue could be improved by increasing the landings at a higher level of technical efficiency. Therefore, the potential still exists for increasing the vessel's revenue without increasing its landings by applying suitable fish-market systems and improving catch preservation methods onboard the vessels in order to get higher prices for the fish catch.

The estimates of the technical inefficiency could provide helpful information for improving the performance of the Da Nang-based gillnet vessels. For example, the vessel owners could increase their gross revenue by helping many crew members to contribute some gillnet sheets that would encourage them to work harder and take on more responsibilities for the vessel's operations. The technical efficiency of gillnet vessels could also increase if the owners operate lager vessels (*i.e.* higher engine power), given that everything else remains the same. Furthermore, the owners could also improve vessel efficiency by operating vessels by themselves or employing their relatives to work as a captains.

Conclusion

This research study which assessed the technical efficiency of gillnetters is based on the cross-sectional survey of costs and earnings of sampled Da Nang-based gillnet vessels operating in 2009. The average monthly revenue and inputs used as well as the technical and operational characteristics of the sample gillnetters were examined by applying a translog stochastic production frontier, and developing the model for relevant vessel- and operator-specific technical inefficiencies. The results from the frontier analysis clarified that the effects of technical inefficiencies were considerably significant in explaining the levels of and variation in the vessel's revenues having technical efficiency scores ranging from 0.55 to 0.98 with mean of 0.76. Some relevant vessel- and operator-specific variables such as engine power, vessel age, and number of gillnet contributors were found to be the key factors that influenced the technical efficiency. A vessel with bigger engine power tends to be more efficient than those with lesser engine capacities, while vessel's age also had strong negative influence on technical efficiency which confirmed that newer vessels seem to operate more efficiently than the older vessels. Gillnet vessels with more net contributors also attained relatively more efficient gains than those with less contributors.

The results also indicated that production from the gillnet fishery of Da Nang could be characterized by increasing "returns to scale". This implied that gillnetters in 2009 could have increased their average monthly gross revenue by more than 32% by operating at full technical efficiency. The estimates of the marginal productivities of inputs also suggested that it would be economical for gillnet vessels to operate with more variable costs incurred or longer gillnet sheets used in fishing and/or additional crew members employed.

Since this study relies on a cross-sectional survey (in 2009) of the sample gillnet fisheries, a single observation per vessel was examined. Thus, the efficiency analysis based on the given data could be subjected to problems which could make the results of the stochastic production frontier analysis less reliable. In addition, the choice of input measurements used in the estimated frontier models may also lead to certain bias in the estimated results. Other factors could also have limited the accuracy of the results, considering that the study used reliable data (a true record) of the total variable costs and cross revenue per month by each vessel collected from the fisher's logbook records, while various relevant information about the socio-economic factors of fishers were very difficult to obtain through face-to-face interviews because of relatively low literacy and less cognition of most fishers, and with limited time and financial constraints of the study. Nonetheless, the estimation of the production frontier in this study required strong distributional assumptions on the error components in order to separate the stochastic (statistical noise) and inefficiency effects in the model.

As a result, the reliability of the assumptions in the study could not be well documented. Therefore, further work is recommended to improve the gillnet efficiency estimation by collecting more data (panel data) with higher number of gillnet vessels in the sample. In addition, a suitable logbook should be designed by proper authorities and provided to all fishers, and that appropriate training on the use of the logbook should be conducted especially for the skippers. It is important that a good database should be developed that could be used for fisheries management and research purposes, because the present logbook systems which mainly focused on variable costs and total gross revenue data, need to be improved to include other important socio-economic information.

In other words, this study also could not exactly determine the effects of the availability of fish stocks, onboard technology including equipment used, and seasonal variation on the performance of the gillnet vessels because of insufficient information or inadequate observations in the sample. Allocative and scale efficiencies are also important issues that should be addressed in fisheries management. However, these topics have not been included in this study because of data constraints, making it necessary to undertake further studies in order to evaluate such aspects for the gillnet fisheries in Da Nang or in other areas, in due time.

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