Estimating technical efficiency of the coastal purse seines fishery using a stochastic frontier analysis

Do-Hoon Kim*, Jung-Sam Lee** and Ju-Nam Seo***

ABSTRACT

This study analyzes the technical efficiency of the coastal purse seine fishery in Korea, using the stochastic frontier analysis (SFA). A Cobb-Douglas production function with inefficiency represented by a half-normal distribution was set up; and the output variable was the total production value and the input variables were physical production factors directly related to fishing activities of vessels, i.e. the numbers of tons, fishing days and crew size.

The average technical efficiency of the sample vessels, estimated by SFA, was 60%, which meant there was a relatively high degree of inefficient production in the vessels. The technical efficiencies for each vessel were observed to spread evenly over a wide range between 14% and 100%. In addition, there was statistically significant difference in the technical efficiencies by vessel size: the technical efficiency was highest in the vessels of 5 tons and more, followed by those of less than 3 tons and those of 3-5 tons.

Key words: technical efficiency, stochastic frontier analysis, coastal purse seine fishery, productivity

* Corresponding Author : Research Specialist, The National Fisheries Research & Development Institute, 408-1, Sirang-ri, Gijang-Eup, Gijang-Kun, Busan, Korea. E-mail : delaware310@nfrdi.go.kr, Tel. : +82-51-720-2771.

** Senior Researcher, Fisheries Policy Research Division, Korea Maritime Institute, 1652, Sangam-dong Mapo-gu, Seoul, 121-270, Korea

*** Research Specialist, The National Fisheries Research & Development Institute, 408-1, Sirang-ri, Gijang-Eup, Gijang-Kun, Busan, Korea

1. Introduction

Technical efficiency is an important index to decide whether a specific firm is productive or profitable since it is to measure production efficiency derived from input and out factors of the firm. Comparison of efficiencies of firms enables each firm to examine and improve its management and to set up management strategies. In addition, technical efficiencies can be used to figure out the productivity level of firms of a single industry and to compare it with that of other nations, so that they would be critical data for formulating policies for industrial development. In particular, analysis of technical efficiencies is useful for assessing effects of policy regulations and/or systems and new technology development and application on firms.

Analysis of technical efficiencies has been applied for various industrial sectors such as banking, manufacturing and tourism businesses (Park, 2008; Kim *et al*., 2007; Okeahalam, 2006). For the fishing industry, such as longline fishery of Hawaii (Sharma and Leung, 1999) and scallop fishery of the mid-Atlantic (Kirkley *et al*., 1995), technical efficiencies were estimated. As the issue of fishing capacity management came to the fore across the world in the 2000s, methods to analyze technical efficiencies, as a way to measure a fishing capacity, have been domestically and internationally researched (FAO, 2004; Kim, 2006; Kirkley *et al*., 2001).

As a method to estimate technical efficiencies, Data Envelopment Analysis (DEA), a non-parametric technique and Stochastic Frontier Analysis (SFA), a parametric technique, have been generally applied. DEA has the advantages that it does not require weights for input and output factors and can include a number of output factors in efficiency estimation. But it has shortcomings that measurement errors are included as a factor of inefficiency so that the degree of inefficiency can be exaggerated and that it is hard to statistically estimate and select input variables. On the other hand, SFA has some advantages that it is possible to verify statistically input variables, which, as a feature of parametric techniques, is difficult in DEA methods and that errors of measurement can be divided and estimated as random error and inefficiency.

The purpose of this study is to analyze technical efficiency of a coastal purse seine fishery in Korea, using the SFA. Considering the situation that recent changes in the domestic and international fisheries require the Korean government to set up various policies to stabilize, strengthen and restructure the coastal fisheries, the study is expected to present basic data and methodology for framing and implementing such policies. Chapter 2 introduces the SFA technique and data used for analysis; Chapter 3 shows results of the analysis; and the study ends in Chapter 4 with summary and conclusion.

2. Analytical method and data

2.1 Stochastic frontier analysis (SFA)

The stochastic frontier production function for cross-sectional data is defined as:

$$y_i = f(x_i;\beta) + v_i - u_i \tag{1}$$

where, y_i denotes the production of the $i-th$ sample firm ($i = 1, 2, ..., n$); x_i is a $(1 \times k)$ vector of functions of input quantities used by the $i-th$ firm; β is a $(k \times 1)$ vector of parameters to be estimated; the v_is are assumed to be independently and identically distributed $N(0, \sigma_v^2)$ random errors, independent of the u_is are non-negative random variables, associated with technical inefficiency in production, which are assumed to be independently and identically distributed and truncations (at zero) of the normal distribution with mean, 0 and variance, σ_u^2 $[u_i \sim N^+(0, \sigma_u^2)]$.

Assuming the half-normal distribution of the error term, where $\epsilon_i = v_i - u_i$, it satisfies the following conditions; (i) $v_i \sim iidN(0, \sigma_v^2)$ and it is called the symmetric error component; (ii) $u_i \sim iidN^+(0, \sigma_u^2)$, i.e. non-negative half-normal distribution and it is called the one-sided error component; and (iii) u_i and v_i are distributed independently of each other and of the regressors.

The density function of $u \geq 0$ and the density function of v are described as follows, respectively.

$$f(u) = \frac{1}{\sigma_u \sqrt{2\pi}} \cdot exp\left(-\frac{u^2}{2\sigma_u^2}\right) \text{ and } f(v) = \frac{1}{\sigma_v \sqrt{2\pi}} \cdot exp\left(-\frac{v^2}{2\sigma_v^2}\right) \tag{2}$$

Given the independence assumption, the joint density function of u and v is as follows.

$$f(u, v) = \frac{2}{2\pi\sigma_u\sigma_v} \cdot exp\left(-\frac{u^2}{2\sigma_u^2} - \frac{v^2}{2\sigma_v^2}\right) \tag{3}$$

Since $\epsilon = v - u$, the marginal density function of ϵ is obtained as follows.

$$\begin{aligned} f(\epsilon) = \int_0^\infty f(u, \epsilon)du &= \frac{2}{\sqrt{2\pi}\sigma} \cdot \left(1 - \Phi\left(\frac{\epsilon\lambda}{\sigma}\right)\right) \cdot exp\left(-\frac{\epsilon^2}{2\sigma^2}\right) \\ &= \frac{2}{\sigma} \cdot \phi\left(\frac{\epsilon}{\sigma}\right) \cdot \Phi\left(-\frac{\epsilon\lambda}{\sigma}\right) \end{aligned} \tag{4}$$

where, $\sigma = (\sigma_u^2 + \sigma_v^2)^{1/2}$, $\lambda = \sigma_u / \sigma_v$ and $\Phi(\cdot)$ and $\phi(\cdot)$ are the standard normal cumulative distribution and density functions.

The marginal density function $f(\epsilon)$ is asymmetrically distributed. Its respective mean and variance are as follows.

$$E(\epsilon) = -E(u) = -\sigma_u \sqrt{\frac{2}{\pi}} \text{ and } V(\epsilon) = \frac{\pi - 2}{\pi}\sigma_u^2 + \sigma_v^2 \tag{5}$$

Using equation (4), the log likelihood function for a sample of I firms is as follows.

$$lnL = constant - Iln\sigma + \sum_i ln\Phi\left(-\frac{\epsilon_i \lambda}{\sigma}\right) - \frac{1}{2\sigma^2}\sum_i \epsilon_i^2 \tag{6}$$

The log likelihood function in equation (6) can be maximized with respect to the parameters to obtain maximum likelihood estimates of all parameters. These estimates are consistent as I approaches to infinity. In addition, the conditional distribution of u_i, given ϵ_i, is as follows.

$$f(u \mid \epsilon) = \frac{f(u, \epsilon)}{f(\epsilon)} = \frac{1}{\sqrt{2\pi}\sigma_*} \cdot exp\left(-\frac{(u - \mu_*)^2}{2\sigma_*^2}\right) \Big/ \left(1 - \Phi\left(-\frac{\mu_*}{\sigma_*}\right)\right) \tag{7}$$

where $\mu_* = -\epsilon\sigma_u^2/\sigma^2$ and $\sigma_*^2 = \sigma_u^2\sigma_v^2/\sigma^2$. Since $f(u \mid \epsilon)$ is distributed as $N^+(\mu_*, \sigma_*^2)$, either the mean or the mode of this distribution can serve as a point estimator for u_i, which is defined respectively as follows.

$$E(u_i \mid \epsilon_i) = \mu_{*i} + \sigma_*\left(\frac{\phi(-\mu_{*i}/\sigma_*)}{1 - \Phi(-\mu_{*i}/\sigma_*)}\right) = \sigma_*\left(\frac{\phi(\epsilon_i\lambda/\sigma)}{1 - \Phi(\epsilon_i\lambda/\sigma)} - \left(\frac{\epsilon_i\lambda}{\sigma}\right)\right)$$

$$\text{and } M(u_i \mid \epsilon_i) = \begin{cases} -\epsilon_i\left(\dfrac{\sigma_u^2}{\sigma^2}\right) & \text{if } \epsilon_i \le 0 \\ 0 & otherwise \end{cases} \tag{8}$$

Once point estimates of u_i are obtained, estimates of the technical efficiency of i-th firm (TE_i) can be obtained from the equation (9).

$$TE_i = exp(-u_i) \tag{9}$$

In order to see how technical inefficiency influenced the production variances of the samples during the period, $\lambda = \sigma_u^2/\sigma_v^2$ is introduces. That is, when λ approaches to 0 (because of either $\sigma_v^2 \rightarrow \infty$ or $\sigma_u^2 \rightarrow 0$), the symmetric error component dominates the one-sided error in the determination of ϵ. On the other hand, as λ approaches infinity, the one-sided error component dominates the symmetric error component in determining ϵ. It means that a large value of λ indicates a large portion of the production variance is attributed to the technical inefficiency error (σ_u^2) and vice versa (Kumbhakar and Lovell, 2000). The frontier production for i-th firm is computed as its actual production divided by its technical efficiency estimate.

2.2 Data

The coastal purse seine fishery is a sector of the fishing industry where non-power vessels or power vessels not exceeding 8 tons catch marine animals with purse seines or ring nets. The yearly production of the domestic coastal purse seine fishery was 130 tons in 1990 and increased continually to about 2,400 tons in 1998 and after that, showed a remarkable surge as nearly 8,000 tons in 2004. It reached the highest point of 16,000 tons (valued at 17.63 billion won) in 2008 thanks to the increase in production of anchovies and herrings.

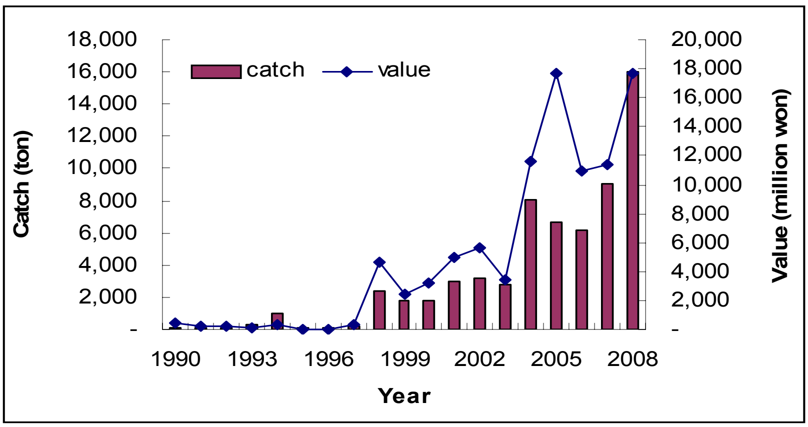

Figure 1. Changes in catch and values of coastal purse seine fishery (1990~2008)

In the average catches for the last 3 years (2006~2008) of coastal purse seine fishery, the fish produced in the largest amount was anchovies (59.8%), followed by herrings (24.0%), saurels (6.0%), gizzard shads (3.6%) and sauries (1.4%). And the fish with the highest monetary value in production was anchovies (61.2%), followed by gizzard shads (11.3%), herrings (9.6%) and saurels (3.7%).

For this study, the data of 275 fishing business units (vessels) of coastal purse seine fishery which had been collected as the samples for the 2005 fishing industry survey were used. The data of production value, instead of landings due to the data unavailability, were used as an output variable in analyzing technical efficiencies by SFA. Those business units of coastal purse seine fishery had caught various fishes such as anchovy, herring and saurel, but the production values per fish were summed up and the full amount of values was used as an output variable. And the three input variables used in the analysis were physical production factors in direct relations with fishing activities of vessels, i.e. the numbers of tons, fishing days and employed people. Table 1 shows descriptive statistics of the used variables.

Table 1. Summary statistics for variables used in the efficiency analysis

Variable	Mean	Standard deviation	Minimum	Maximum
Production value (10 thousand won)	3,620.3	4,115.6	75	15,000
Trip days (day)	168.5	62.6	30	305
Tonnage (ton)	4.0	2.8	0.08	8.0
Employed people (number)	3.6	2.9	1	15

The average production value of the sample vessels for coastal purse seine fishery, which were figured out by summing up the production values of each fish, was nearly 36.20 million won and the deviation among the productions per vessel was found out to be quite large according to the numbers of fishing days and the scales of vessels. As for the input variables, the mean of the fishing days of the vessels was 169 days in a year, the mean tons of the vessels were 4 tons and the mean number of the people working in the vessels was surveyed to be 3.6.

3. Results

The form of production functions used in applying the SFA technique to coastal purse seine fishery was the Cobb-Douglas production function as shown in the following equation 10.

$$lnsale_i = \alpha_0 + \alpha_1 lntrip_i + \alpha_2 lnton_i + \alpha_3 lnemp_i + v_i - u_i \tag{10}$$

In the function, i is the i-th vessel of the sample vessels; $sale$ is the output variable, a production value; and as the input variables, $trip$ is the number of fishing days, ton is the number of tons and emp is the number of employed working people; and v and u are the non-negative variables associated with the random error term and inefficiency as said above.

The production function in the equation 10 according to the SFA method is estimated by Maximum Likelihood Estimation (MLE) and the variance is $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\lambda = \sigma_u / \sigma_v$. Table 2 shows the result of assuming the production function in the equation 10 by SFA.

Table 2. Parameter estimates of stochastic production frontier

Variables	Parameter	Coefficient	Standard-error
Constant	α_0	6.155***	0.834
lntrip	α_1	0.306**	0.147
lnton	α_2	0.361***	0.079
lnemp	α_3	0.398***	0.103
σ^2		1.962***	0.111
λ		1.401***	0.368
σ_u [H_0: σ_u=0]		4.550***	
Log(likelihood)		-405.912***	

Notes: **statistically significant at the 0.05 level. ***statistically significant at the 0.01 level.

As a result of analysis, the coefficients of parameters for all the variables were estimated to be statistically significant within the level of 5%; the sum (σ^2) of the error variances of the production function was found out to be statistically significant and of the error variances, the weight (λ) for the part described by technical inefficiency was analyzed to be statistically significant as 1.401. Therefore, the part of technical inefficiency in the error term of the assumed production function is important as to determine the degree and range of production of a vessel for coastal purse seine fishery.

In the log-log Cobb-Douglas production function, the coefficients of parameters mean the output elasticity of an input variable. The output elasticities of all the input variables were figured out to be positive numbers: the elasticity was highest (0.398) for the number of working people, followed by the number of tons (0.361) and the number of fishing days (0.306). The value of the returns to scale of the coastal purse seine fishery, for which the output elasticities of all the input variables were summed up, was 1.065. As a finding of the statistical verification for the null hypothesis ($\alpha_1 + \alpha_2 + \alpha_3 = 1$), it did not reject the null hypothesis, so the production of the coastal purse seine fishery was considered to have a constant returns to scale.

The average technical efficiency of the coastal purse seine fishery, estimated by SFA, was 0.60 (0.14~1.00), so inefficient production of the vessels was found to be quite high. It was, thus, thought that the productivity of coastal purse seine fishery would increase by a large number once efficient production gets realized by vessels. To be specific, Table 3 shows the estimates of the technical efficiencies for each vessel. The difference in the technical efficiencies was found out to be significantly large per vessel, based on the finding that the number of the vessels with the technical efficiency being 1 was 46 (17%) and that of the vessels with the technical efficiency being more than 0.8 was 78 (28%), while that of the vessels with the technical efficiency being less than 0.5 was 107 (40%).

Table 3. Frequency distribution of technical efficiency (TE) from the SFA

Efficiency score	Number of vessels
< 0.30	46
0.30~0.40	28
0.40~0.50	33
0.50~0.60	35
0.60~0.70	29
0.70~0.80	26
0.80~0.90	23
0.90~1.00	9
1.00	46
Mean	0.60
Minimum	0.14
Maximum	1.00
Standard deviation	0.28

To obtain a specific range of technical efficiencies per vessel, the mean values of technical efficiencies for each scale of vessels were figured out and the difference in the technical efficiencies among the vessels of different scales was verified by analysis of variance (ANOVA). As shown in Table 4, the vessels were divided into those of less than 3 tons, 3 tons to less than 5 tons and 5 tons and more and the average technical efficiencies for each scale were estimated.

The average technical efficiency was highest in the vessels of 5 tons and more (0.648), followed by those of less than 3 tons (0.576) and those of 3 tons to less than 5 tons (0.562). As a result of ANOVA for the difference of technical efficiencies among the vessels of different scales, the difference was found out to be statistically significant at the level of 10%, so it was considered that there is difference in technical efficiencies of vessels according to vessel scales.

Table 4. Results of ANOVA analysis

Vessel tonnage	Sample size	Relative efficiency	Std. Dev.	F-statistics (p-value)
less than 3ton	122	0.576	0.282	2.457 (0.088)*
between 3ton and 5ton	61	0.562	0.255	
over 5 ton	92	0.648	0.280	

Notes: *statistically significant at the 0.10 level.

4. Summary and conclusions

In this study, technical efficiencies of coastal purse seine fishery in Korea were estimated by SFA. For the SFA method, the Cobb-Douglas production function where the inefficiency term is assumed to have a half-normal distribution was used; and the output variable was the total production value, for which production values of each fish were summed up and the input variables were physical production factors, i.e. the numbers of tons, fishing days and employed working people.

The average technical efficiency of the sample vessels for coastal purse seine fishery, estimated by SFA, was 60%, which meant there was a relatively high degree of inefficient production in the vessels. It was, thus, expected that productivity and profitability of coastal purse seine fishery would increase by a large number once efficient production gets realized by vessels. Based on the results of the analysis on technical efficiencies, the production of coastal purse seine fishery was estimated to increase by 36.6% at maximum if efficient production is made possible by vessels. The technical efficiencies for each vessel were observed to spread evenly over a wide range between 14% and 100%.

As a result of analyzing the difference in technical efficiencies among the vessels of different scales, there was statistically significant difference in the technical efficiencies according to vessel scales: the technical efficiency was highest in the vessels of 5 tons and more (0.648), followed by those of less than 3 tons (0.576) and those of 3 tons to less than 5 tons (0.562). Therefore, as shown in the output elasticities of the input variables, it was thought that enlargement of vessel scale would lead to increase in vessel productivity.

Since this study used data of a year in analyzing technical efficiencies of coastal purse seine fishery, it was impossible to present changes in technical efficiencies of coastal purse seine fishery with time. Therefore, the results of the study would have limitations in generalizing technical efficiencies of coastal purse seine fishery. It was, however, considered that the study is meaningful as a static analysis, in the sense that it was conducted to understand the present degree of technical efficiencies of coastal purse seine fishery and based on the understanding, suggested management strategies and policies for each vessel to improve in productivity and profitability.

Lastly, it is hoped that further research into related data and dynamic analyses on changes in technical efficiencies will enable us to take more useful management strategies and policies for improving productivity and profitability of coastal purse seine fishery.

References

FAO, 2004. Measuring and assessing capacity in fisheries : Issues and methods. *FAO Fisheries Report* 433(2), Rome.

Kim, D. H., 2006. Measurement of fishing capacity of offshore fisheries in Korea, *Journal of Fisheries Business Administration* 37(1), pp.1~24.

Kim. S. H., T. S. Choi and D. W. Lee, 2007. *Efficiency Analysis: Theory and Application. Seoul Economic and Management Press*, p.362.

Kirkley. J. E. *et al.,* 2001. Assessing capacity and capacity utilization in fisheries when data are limited, *North American Journal of Fisheries Management* 21, pp. 482~497.

Kirkley J. E., D. Squires and I. E. Strand, 1995. Assessing technical efficiency in commercial fisheries: The mid-atlantic sea scallop fishery, *American Journal of Agricultural Economic* 77, pp.686~697.

Kumbhakar, S. C. and C. A. Lovell, 2000. *Stochastic Frontier Analysis*, Cambridge University Press. p.333.

Okeahalam, C. C., 2006. Production efficiency in the south african banking sector: A stochastic analysis, *International Review of Applied Economics* 20(1), pp.103~123.

Park, M. H., 2008. *Efficiency and Productivity Analysis*. Korea Studies Information Co. Ltd. p.225.

Sharma, K. R. and P. Leung, 1999. Technical efficiency of the longline fishery in hawaii: An application of a stochastic production frontier, *Marine Resource Economics* 13, pp.259~274.