Technical efficiency of the coastal composite fishery in Korea: a comparison of data envelopment analysis and stochastic frontier analysis †

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Ⅰ. 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 output and input factors of the firm. Comparison of efficiencies of firms enables an individual firm to examine and improve its business conditions and to establish management strategies. Furthermore, technical efficiencies can be utilized to figure out the productivity level of firms of a certain industry and to compare it with that of other countries, so that they would be important data for establishing policies for the economically viable and competitive development of an industry.

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Owing to its usefulness and importance, estimation of technical efficiency has been applied for various industries such as banking, manufacturing and tourism businesses (Fried et al., 1993; Hwang and Chang, 2003; Kim et al., 2007). In particular, for fisheries, as the issue of fishing capacity management came to the fore across the world in the 2000s, technical efficiencies have been estimated internationally and domestically (Kim, 2006; Kirkley et al., 1995; Pascoe et al., 2001; Sharma and Leung, 1999; Tsitsika et al., 2008; Zheng and Zhou, 2005).

As methods 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. However, it has shortcomings that measurement errors can be included as a factor of inefficiency so that the degree of inefficiency may 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 the DEA method and that errors of measurement can be divided and estimated as random error and inefficiency. Its weaknesses include that the form of production function and the distribution of inefficiency are required to be assumed in advance (Cooper et al., 2007; Kumbhakar and Lovell, 2000; Minh et al., 2007). The shortcomings that DEA and SFA have can be partially supplemented by utilizing both methods together, however few investigation has been made on this issue yet.

In this study, the technical efficiency of coastal composite fishery which has the largest scale of fishing catches among the coastal fisheries of Korea, was estimated by using both DEA and SFA methods, and the results on the respective methods were compared. Under the present situation when policy formulation aimed at management stabilization and competitiveness enhancement of coastal fisheries as well as provision of various policy alternatives for restructuring coastal fisheries are urgently required due to changes of global and domestic fishery conditions, this study is expected to suggest data and methodologies for such policy formulation and execution. Specifically for analyses, in the DEA method, the constant returns to scale (CRS) model and the variable returns to scale (VRS) model were separated and technical efficiencies were estimated, respectively. The results were then subsequently compared with the estimation result by the SFA method.

Ⅱ. Methods and Data

1. Stochastic frontier analysis

In stochastic frontier analysis (SFA) method, the relationship between input variables and output variables is described in the form of production function, and error terms are marked as divided into the probability error term and the term that reflects technical inefficiency (Aigner et al., 1977; Kumbhakar and Lovell, 2000). That is, the function that displays maximum output when a certain quantity of production elements was inputted under the present technology level, is defined as the equation 1:

$$y_i = f(x_i;\ \beta)\ e^{v_i} e^{u_i} \qquad (1)$$

And in case log is taken at both sides of production function in the equation 1, the stochastic frontier production function can be displayed as shown in the equation 2:

$$y_i' = f(x_i';\ \beta) + v_i - u_i \qquad (2)$$

where, it means that $y_i' = \log y_i$ and $x_i' = \log x_i$, while y_i denotes the production of the $i-$th fishing vessel (i=1, 2,...., n), x_i is a $(1\times k)$ vector of input element function of the $i-$th vessel, and β is a $(k\times 1)$ vector of the parameters to be estimated. Also, v_i is assumed to be an independently and identically distributed random error and u_i is a non-negative random variable, associated with technical inefficiency in production of the $i-$th vessel.

Assuming that inefficiency variable, u_i, follows the truncated-normal distribution $[N^+(\mu, \sigma_u^2)]$, the case of $u_i=0$ means that efficient production is implemented, and $u_i > 0$ means that inefficient production is implemented. Under the assumption of truncated-normal distribution, the expected value $[E(u_i|\varepsilon_i)]$ of conditional distribution of inefficiency u_i to the composed error terms $(\varepsilon_i = v_i - u_i)$, is induced as shown in the equation 3.

$$E(u_i|\varepsilon_i) = \frac{\sigma\gamma}{(1+\gamma^2)}\left[\frac{\phi(u^*)}{1-\Phi(\mu^*)} - \mu^*\right] \qquad (3)$$

where, $\mu^* = (\varepsilon\gamma + \sigma) + (u/\sigma\gamma)$, $\gamma = \sigma_u/\sigma_v$, $\sigma = (\sigma_v^2 + \sigma_u^2)^{1/2}$, and $\Phi(\cdot)$ and $\phi(\cdot)$ are the standard normal cumulative distribution and density functions, respectively. Based on the results of equation 2 and 3, estimates of the technical efficiency of the $i-$th vessel (TE_i) can be obtained from the equation 4.

$$TE_i = \exp(-u_i) \tag{4}$$

The maximum (frontier) production for the i－th vessel is computed as its actual production divided by its technical efficiency estimate. In addition, from the coefficients of the production function, the elasticity of output (ε_k) with respects to the kth input variable can be evaluated and the measure for returns to scale (RTS) can be estimated as the sum of output elasticities for all inputs. When the translog function is assumed as the form of production function, the elasticity of output with respects to the kth input variable is derived as the equation 5.

$$\varepsilon_k = \frac{\partial \ln y}{\partial \ln x_k} = a_k + 2\alpha_{kk} \ln \overline{x_k} + \sum_{j \neq k} a_{kj} \ln \overline{x_{ji}} \tag{5}$$

where $\overline{xs}$ are the means of input variables used in the stochastic frontier production function.

2. Data envelopment analysis

Data envelopment analysis (DEA) is a linear programming methodology to measure the efficiency of multiple firms when the production process presents a structure of multiple inputs and outputs. Assuming the situation with n firms, each firm producing single output by using m different inputs, the variable returns to scale (VRS) output-oriented DEA model for the i－th firm is shown as the equation 6.

$$\max \phi_i \tag{6}$$

subject to:

$$\sum_{j=1}^{n} \lambda_j y_j - \phi_i y_i - s = 0$$

$$\sum_{j=1}^{n} \lambda_j x_{kj} + e_k = x_{ki} \qquad k=1,\cdots.., \text{m inputs;}$$

$$\sum_{j=1}^{n} \lambda_j = 1 \qquad j=1,\cdots.., \text{n firms;}$$

$$\lambda_j \geq 0;\ s \geq 0;\ e_k \geq 0$$

where ϕ_i is the proportional increase in output possible for the i－th firm, s is the output slack, e_k is the k－th input slack, and λ_j is the weight of the j－th firm. The constant returns to scale (CRS) output-oriented model can be obtained by eliminating one of constraints, $\sum_{j=1}^{n} \lambda_j = 1$, in the equation 6.

The frontier production level for the i－th firm, denoted by $\hat{y}_i$ can be can be calculated as shown in the equation 7.

$$\hat{y}_i = \sum_{j=1}^{n} \lambda_j y_j = \phi_i y_i \quad (7)$$

The output – oriented measure of technical efficiency of the i – th firm(TE_i) is estimated by the equation 8.

$$TE_i = \frac{y_i}{\hat{y}_i} = \frac{1}{\phi_i} \quad (8)$$

The technical efficiency estimate of the i – th firm in the CRS output-oriented model ($TE_{i,\ CRS}$) would be less than or equal to that in the VRS output-oriented model ($TE_{i,\ VRS}$). However, the relation between $TE_{i,\ CRS}$ and $TE_{i,\ VRS}$ can be used to estimate a measure of scale efficiency of the i – th firm (SE_i) as shown in the equation 9.

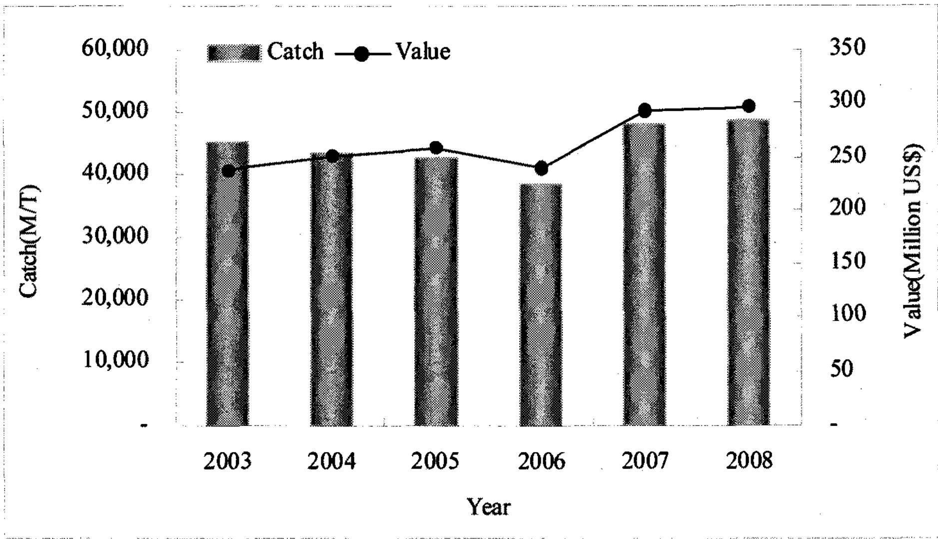
$$SE_i = \frac{TE_{i,\ CRS}}{TE_{i,\ VRS}} \quad (9)$$

where $SE_i = 1$ implies scale efficiency and $SE_i < 1$ indicates scale inefficiency. Scale inefficiency is due to either increasing or decreasing returns to scale which can be estimated by investigating the sum of weights ($\sum_{j=1}^{n} \lambda_j$), under the specification of CRS. That is, if the sum is equal to one, it shows constant returns to scale, if it is less than one it implies increasing returns to scale, and it is greater than one it indicates decreasing returns to scale.

3. Coastal composite fishery

Coastal composite fishery is a fishing sector that catches fishery resources by using longline, jigging, octopus trap gears, etc. on board non-motorized vessel or motorized vessel of tonnage less than 10 tons. The total number of fishing vessels engaged in coastal composite fishery of Korea is 27,395 as of 2008, commanding about 51% of total coastal fishing vessels 53,792. The production quantity of coastal composite fishery in 2008 was about 49 thousand tons, which is equivalent to US$ 296 million in production value (MIFAFF, 2009).

To review in detail the trend of production quantity and value of coastal composite fishery since 2003 when statistical aggregate began officially, the production quantity in 2003 was about 45,404 tons but it showed downward pace, to record 38,580 tons in 2006. But the quantity rose to 48,318 tons in 2007, and then it recorded 48,546 tons in 2008. On the basis



<Fig. 1.> Production quantity and value of coastal composite fishery (2003-2008)

of such trend in production quantity, the production value of coastal composite fishery was about US$ 237 million in 2003, then it rose to US$ 294 million in 2007 when the catches increased sharply. As of 2008, the production value of coastal composite fishery stands at around US$ 296 million as shown in ⟨Fig. 1⟩.

Diverse kinds of species are caught in the coastal composite fishery, such as squid, hairtail, webfoot octopus, small octopus, gizzard shad and yellow croaker. Reviewing the average fishing catches in recent 3 years (2006～2008) per kind of species, in production quantity, squid commands the largest share (22.5%), followed by hairtail (19.5%), small octopus (8.1%) and webfoot octopus (7.7%). In production value, however, hairtail had the largest share (18.2%), followed by small octopus (17%) and webfoot octopus (9.1%).

4. Analytical data

In estimating technical efficiency of coastal composite fishery, the data on 884 sample vessels which had been collected in the national fishery survey 2005 were used. As an output variable used in estimating technical efficiency by SFA and DEA methods, the data of annual production value per vessel were used instead of production quantity owing to limitation in available data. As mentioned earlier, diverse kinds of species are caught in the coastal composite fishery, but the production value per species were summed up and the total production value was used as an output variable.

⟨Table 1⟩ Summary statistics for variables used in the efficiency analyses

Variable	Mean	Standard deviation	Minimum	Maximum
Production value (US$)	18,881	23,273	6,818	136,364
Fishing days (day)	158.5	67	30	335
Tonnage (ton)	2.7	2.4	0.03	9.9
Working fishermen (number)	2.0	1.2	1.0	11.0

As input variables, three kinds of variable were used in this study, taking into account variables used in the previous studies (Kirkley et al., 1995; Sharma and Leung, 1999). Specifically, tonnage of fishing vessel (ton), number of fishing days (day) and number of fishermen (nwf) were used, all of which are physical elements of production directly related to fishing activities in the coastal composite fishery. Descriptive statistics on output and input variables used in the analyses are as summarized in ⟨Table 1⟩

The average production value of the sample vessels for coastal composite fishery which were aggregated production values of all species kinds was analyzed to be about US$18,881. It was found that deviation of production values per fishing vessel is relatively large depending on fishing days and vessel size, etc. As for the input variables, the mean of the fishing days of the vessels appeared 159 days in a year, and the tonnage of vessel was 2.7 tons in average, while the mean number of fishermen per vessel was surveyed to be 2 persons in average.

Ⅲ. Results

1. Results by SFA

In estimating technical efficiency of coastal composite fishing vessels, the production function of translog was assumed as the form of production function, shown in the following equation 10.

$$\ln sale_i = \alpha_0 + \alpha_1 \ln day_i + \alpha_2 \ln ton_i + \alpha_3 \ln nwf_i + \alpha_4(\ln day)_i^2 + \alpha_5(\ln ton)_i^2 + \alpha_6(\ln nwf)_i^2 + \alpha_7(\ln day)(\ln ton)_i + \alpha_8(\ln day)(\ln nwf)_i + \alpha_9(\ln ton)(\ln nwf)_i + v_i - u_i \quad (10)$$

where i is the $i-$th sample vessel, sale is the output variable, a production value and as the input variables, *day*, *ton*, and *nwf* are the number of fishing days, the tonnage of fishing

⟨Table 2⟩ Estimates of stochastic frontier production function

Variable	Coefficient	Std.Error
Constant	11.437**	1.79
lnday	−2.220**	0.78
lnton	0.774**	0.29
lnnwf	−0.982*	0.56
$(lnday)^2$	0.280**	0.09
$(lnton)^2$	0.083**	0.03
$(lnnwf)^2$	−0.122	0.11
$(lnday)(lnton)$	−0.111*	0.06
$(lnday)(lnnwf)$	0.306**	0.11
$(lnton)(lnnwf)$	0.055	0.09
α^2	10589**	0.18
γ	1.332*	0.17
$\sigma_u[H_0 : \sigma_u=0]$	7.55**	
Log-likelihood	−1,223.94**	

**statistically significant at the 0.01 level. *statistically significant at the 0.10 level.

vessel, and the number of working fishermen, respectively. v and u are the independently and identically distributed random error and inefficiency as mentioned above. Assuming that inefficiency variable, u_i, follows the truncated−normal distribution $[N^+(\mu, \sigma_u^2)]$, the variance parameters in terms of $\sigma^2=\sigma_v^2+\sigma_u^2$ and $\gamma=\sigma_u+\sigma_v$(Kumbhakar and Lovell, 2000). The result of estimating production function by the SFA method is as shown in ⟨Table 2⟩ .

As a result of the analysis, the coefficients of parameters for most variables were estimated to be statistically significant and the sum of the error variances (σ^2) was found out to be statistically significant. Furthermore, σ_u among error terms, of inefficiency variable is not statistically zero, being verified as significant so that the assumption on inefficiency was evaluated as good. In particular, the weight (γ) for the part described by production inefficiency was analyzed to be statistically significant as 1.332. 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 value of a vessel for the coastal composite fishery.

Average technical efficiency of the coastal composite fishery by the SFA method was estimated at 0.633, and the frequency distribution of the estimated technical efficiencies for the sample coastal composite vessels is as presented in ⟨Table 3⟩.

To review in detail the distribution of technical efficiency per sample vessel of the coastal composite fishery, the efficiency was estimated to be in the range of 1.00 as maximum value

〈Table 3〉 **Frequency distribution of technical efficiency estimates by SFA**

Efficiency score	Number of sample vessels
〈 0.30	110
0.30 – 0.40	86
0.40 – 0.50	101
0.50 – 0.60	110
0.60 – 0.70	108
0.70 – 0.80	91
0.80 – 0.90	67
0.90 – 1.00	44
1.00	167
Mean	0.633
Minimum	0.140
Maximum	1.000
Standard deviation	0.268

and 0.14 as minimum value. It was also analyzed that the number of vessels with over 0.8 efficiency estimates commanded 31% of total sample vessels, and that the number of fully efficient vessels was found out to be 167 vessels (18.9%).

As defined by the equation 5, the estimated values of output elasticities for all inputs had positive values. The output elasticity to fishing days was found to have the highest value, 0.65, followed by tonnage (0.36) and number of fishermen (0.43) respectively. As a result of estimating the returns to scale (RTS) by summing the output elasticities of these input variables, 1.442 was obtained which is interpreted as increasing returns to scale in case of coastal composite fishery.

2. Results by DEA

In setting and analyzing the DEA model that assumes constant return to scale (CRS) and variable return to scale (VRS) respectively, the output and input variables which are the same as those at the SFA method were used. As a result of analysis, average technical efficiencies by the DEA method under the assumption of constant returns to scale (TE_{CRS}) and variable returns to scale (TE_{VRS}) came out at 0.479 and 0.738 respectively, revealing that the efficiency values estimated under the CRS-DEA model and VRS-DEA model differ largely each other as shown in 〈Table 4〉 . Accordingly, like the analysis result by the SFA method, it was found that technical inefficiency exists to some degree in the coastal composite fishery.

Looking into the frequency distribution of the estimated technical efficiencies for the sample vessels, efficiency values under the VRS-DEA model were estimated to be in the

⟨Table 4⟩ Frequency distributions of technical efficiency estimates by DEA

Efficiency score	Number of sample vessels		
	TE_{VRS}	TE_{CRS}	SE
⟨ 0.30	–	114	52
0.30 – 0.40	–	267	51
0.40 – 0.50	30	189	4
0.50 – 0.60	45	30	427
0.60 – 0.70	288	143	16
0.70 – 0.80	227	78	13
0.80 – 0.90	221	47	5
0.90 – 1.00	51	9	2
1.00	22	7	314
Mean	0.738	0.479	0.663
Minimum	0.449	0.093	0.100
Maximum	1.000	1.000	1.000
Standard deviation	0.119	0.192	0.266

range of 1.00 maximum to 0.449 minimum. The number of fishing vessels with efficiency values between 0.60 and 0.70 was 288 (32.6%), which is the largest figure, and the number of vessels with efficiency values over 0.6 was 809, commanding 92% of total vessels. It was also estimated that the number of fully efficient vessel was 22 (2.5%).

On the other hand, the value of technical efficiency per vessel under the CRS-DEA model was estimated to be in the range of 1.00 maximum to 0.093 minimum, and the number of vessels with efficiency values 0.30 – 0.40 was 267 (about 30%), which is the largest figure. The number of fully efficient vessel was 7 (0.8%), while vessels with less than 0.5 efficiency values appeared to command 64% of total fishing vessels. Moreover, as a result of estimating scale efficiency (SE) based on results of the CRS – DEA model and the VRS – DEA model, average scale efficiency (SE) came out at 0.663.

3. Comparison of efficiency results by SFA and DEA

Comparing the results of analyzing technical efficiency of the coastal composite fishery by SFA and DEA methods, the average estimated value of technical efficiency by the CRS-DEA method was assessed to be lower than that by the SFA method. On the other hand, the average estimated value of technical efficiency by the VRS-DEA method was analyzed to be higher than that by the SFA method. In addition, in analyzing returns to scale, it was concluded that under the SFA method, variable return to scale (increasing return to scale) was

⟨Table 5⟩ Result of Spearman rank correlation coefficient analysis

	TE_{SFA}	$TE_{DEA\text{-}VRS}$	$TE_{DEA\text{-}CRS}$
TE_{SFA}	1.0000		
$TE_{DEA\text{-}VRS}$	0.8261 (0.000)	1.0000	
$TE_{DEA\text{-}CRS}$	0.3471 (0.000)	0.0879 (0.000)	1.0000

*Figures in parentheses indicate *p-values*.

effective, while the average scale efficiency (SE) by the DEA method was estimated at 0.663.

Specifically, to examine the relation degree and agreement between the estimated values of technical efficiency by the two methods, Spearman rank correlation coefficients were analyzed. The results showed, as shown in ⟨Table 5⟩ , that all correlation coefficients appeared to have positive value and that they were estimated to be highly significant statistically. In particular, it was concluded that strong correlations in rankings exist between the SFA method and the VRS-DEA method.

Ⅳ. Discussion and Conclusion

The technical efficiencies of coastal composite fishery, one of largest coastal fisheries in Korea, was estimated by using both the SFA and DEA methods, and efficiency results were compared. As to the SFA method, technical efficiency was estimated by formulating the translog production function that assumes a truncated-normal distribution of inefficient factors. And as to the DEA method, technical efficiencies were estimated by assuming variable returns to scale (VRS) and constant returns to scale (CRS), respectively.

Comparing the average estimated values of technical efficiency by each method, the average estimated value of technical efficiency by the SFA method was found to be lower than that by the VRS-DEA method. However, it was higher than that by the CRS-DEA method. In addition, in the DEA methods, as anticipated, it was concluded that the average estimated value of technical efficiency under the VRS-DEA model was higher than that under the CRS-DEA model.

To be specific, the average technical efficiency of coastal composite fishery by the SFA method was 0.633, and consequently, it was analyzed that the production value would be increased by about 37% in average if efficient production is implemented by each fishing vessel. And the average technical efficiencies of coastal composite fishery estimated by the

VRS-DEA method and the CRS-DEA method were 0.738 and 0.479, respectively. Therefore, it can be expected that the production value could be increased by 26 – 47% if efficient production is made by fishing vessels. That is, if the production value could be increased by pursuing efficient production, it will meet the high fishing costs and enhance fishing competitiveness. It will eventually enable fishing households to grow with reinforced viability and contribute to the economically viable development of fisheries.

Through this study, the method which can utilize both methods in mutually complementing way for the future estimation of technical efficiency could be sought. That is, the combined use of both methods in efficiency estimation can complement the weaknesses retained by each method. For example, in case of the DEA method it is required to assume constant returns to scale (CRS) or variable returns to scale (VRS) in advance to setting model, and the use of results by the SFA method will provide useful information for such model setting. Moreover, in selecting analysis variables, the utilization of SFA will enable the use of variables which are verified statistically. In particular, the combined use of SFA will enable to fathom overestimation or underestimation of inefficiency made by the DEA method. Besides them, in comparing analysis results or grasping scale returns by the SFA method, the comparison with results from the DEA method can provide useful information for improving the accuracy of efficiency estimation.

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Abstract

This study estimated the technical efficiency of coastal composite fishery in Korea by using the data envelopment analysis (DEA) and the stochastic frontier analysis (SFA) methods, and the results on the respective method were compared. In the DEA method, the constant returns to scale (CRS) and the variable returns to scale (VRS) output-oriented DEA models were separated and technical efficiencies were estimated, respectively.

The average estimated value of technical efficiency by the SFA method (0.633) was found to be lower than that by the VRS-DEA method (0.738), while it was higher than that by the CRS-DEA method (0.479). It was found that strong correlation exists between the SFA method and the VRS-DEA method. The method which can utilize both methods in mutually complementing way for the estimation of technical efficiency was also considered.

Key words : Technical efficiency, Stochastic frontier analysis, Data envelopment analysis, Coastal composite fishery, Productivity