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Technical Efficiency of the Driftnet and Payang Seine (Lampara) Fisheries in West Sumatra, Indonesia

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Abstract

This paper examines the production structure of the multi-species, multi-gear fishery in West Sumatra, Indonesia. Majority of the fishermen in this area are still living below the poverty level. This phenomenon is often attributed to low productivity and inefficient use of fishing inputs. Two important fishing gears, driftnet and Payang seine (lampara) were chosen for this study. Using the translog stochastic frontier production function, it was found that about 70 and 100% of the driftnet and lampara fishing units, respectively achieved 90% or even higher technical efficiency. This implies that expansion in fish production for driftnet fishery is still possible by adopting the technology of the highly experienced or well trained fishermen and through optimal resource allocation, although lampara fishery has been operating at the optimal level. Policies to increase fish catch should therefore be focused on driftnet fishing, while effort reduction measures on the other hand should be imposed on lampara fishery.

Introduction

West Sumatra lies between 0° 54' north to 3° 30' south and 98° 36' to 101° 53' east. The marine fishery sector plays an important socio-economic role in this area. In 1996, average landing per gear was 9.6 tons ranging from 0.26 to 461.62 tons. The landing per unit of payang seine (lampara) and driftnet were 8.34 and 2.89 tons respectively. Such low levels of productivity are considered as key factors in explaining poverty among many fishermen in Indonesia (Bailey 1984). The low productivity and persistent poverty among fishermen in West Sumatra may be attributed to technological inefficiency, high levels of resource exploitation, and competition among fishermen for the scarce resources.

Many fishermen in West Sumatra are still living below the poverty line. Despite the growing importance of medium and large-scale fisheries, the small-scale subsector continues to play a vital role in West Sumatra marine fisheries. Small-scale fisheries is characterized by the low level of capital investment and skill (Budiono 1974) required. Sail boats are predominantly used to exploit fishery resources. The high concentration of fishing efforts in the near-shore areas has led to high rates of resource exploitation, low catch per unit effort and low productivity.

West Sumatra has a coastline of 450 km, with a total sea area (inclusive of the EEZ waters) measuring 138,750 km^2. In 1996, about 3.41% of West Sumatra's 4.4 million total population was involved in fishery. The number of fishermen increased from 1990 to 1995 but declined thereafter. Marine fishermen constituted about 21.86% of West Sumatra's fishermen population.

From 1990 to 1996, total fisheries production increased from 69,130 tons to 107,127 tons 76.4% of which was contributed by the marine capture fisheries which showed an increasing trend during the period.

In 1996, out of the 6,796 fishing vessels in West Sumatra (West Sumatra Fisheries Extension Services, 1996), 62.6% were nonpowered while the rest were powered by either inboard or outboard engine. Most of the powered boats however, were small in size. The most widely used fishing gear in the coastal areas were the Danish-seines, lampara, driftnet, lift-net and troll-line, trammer net, scoopnet, longlines, traps and others. These gears, except the troll-line, were used by small-scale fishermen.

The lampara landings have increased from 5,793 tons in 1990 to 7,711 tons in 1996, although there were considerable fluctuations. Initially, marine fish landings increased in 1990, reached the peak (at 10,583 tons) in 1993, then declined in 1995 but recovered in 1996. The main species caught by the lampara fishermen are tuna, little tuna, skipjack and Indian mackerel. Similarly, marine fish landings for driftnet also fluctuated between 1990 and 1996 and showed a similar pattern as that of lampara when it reached the peak landing (3,065 tons) in 1993. Driftnet fishermen catch mainly little tuna, Indian mackerel, Spanish mackerel and scads.

Given the complexity that exists in the West Sumatra fishery such as multi-gear, low catch and low income, policy makers are looking into alternatives to address the fishing communities' poverty problem while trying to manage the fishery on a sustainable basis. Two important aspects that may shed light on fishery policies are the issues of productivity and technical efficiency of the different types of fishing vessels and gears. This study therefore aims to estimate the frontier production function and determine resource use efficiency for the lampara and driftnet vessels in West Sumatra.

Materials and Methods

The stochastic frontier production model and technical efficiency

The long-run fishery production function relates harvest (the output) to both the fish stock and fishing effort (the inputs) (Anderson 1986, Panayotou 1985). In the short-run however, fish stock is considered as fixed and only fishing effort varies. Thus, a short-run fishery production function can be expressed as:

$$Y = f(E) \quad (1)$$

where Y is catch and E is fishing effort. Fishing effort is a composite index of inputs such as vessels, gear, fuel, labor and management ability which can be written as:

$$E = g(E_1, E_2, \ldots\ldots , E_5) \quad (2)$$

Substituting equation 2 into equation 1, fishery production function then can be written as:

$$Y = f_1(E_1, E_2, \ldots\ldots , E_5) \quad (3)$$

The frontier production function represents the widely used technology by firms in an industry. The stochastic frontier production model has been suggested to measure the technical efficiency of firms (Richmond 1974, Aigner et al. 1977, Battese and Corra 1977, Collie 1995). The model can be expressed as:

$$Y_i = f(Xi, \beta) \exp\varepsilon_i \quad (4)$$

where β's are the parameters to be estimated, X_i's are the fishing inputs and $\varepsilon_i = v_i + u_i$. The errors u_i are assumed to be negative and arise due to the truncation of the normal distribution with zero mean and positive variance σ_u^2. It represents a firm's technical efficiency of production. On the other hand, errors v_i are assumed to have normal distribution with zero mean and positive variance σ_v^2, representing 'measurement error' associated with uncontrollable factors related to the production process.

The technical efficiency can be measured using a variance ratio parameter denoted by g as follows (Battese and Corra 1977):

$$\gamma = (\sigma_u^2) / (\sigma^2) \quad (5)$$

where $\sigma^2 = \sigma_u^2 + \sigma_v^2$, and $0 \leq \gamma \leq 1$

When γ tends to 1, σ_v^2 tends to zero and u_i is the predominant error in equation 5, that implies technical inefficiency. In this case, the difference between the firm and efficient output is mainly due to firm's specific variability. Thus further analyses are possible to identify the factors responsible for such difference. On the other hand, when γ tends to zero, the symmetric error v_i is predominant. In this case, not much can be done to reduce the difference between firm and efficient output.

Jondrow et al. (1982) showed that the conditional mean of u_i given ε_i is equal to:

$$E(u_i \mid \varepsilon_i) = (\sigma_u \sigma_v /\sigma)\{[f(\varepsilon_i\lambda\sigma^{-1})/(1-F(\varepsilon_i\lambda\sigma^{-1}))] - (\varepsilon_i\lambda\sigma^{-1})\} \quad (6)$$

where ε_i is the sum of v_i and u_i, σ is equal to $(\sigma_u^2 + \sigma_v^2)^{1/2}$, λ is the ratio of σ_u over σ_v, f and F are the standard normal density and distribution functions evaluated at $\varepsilon_i\lambda\sigma^{-1}$. Measures of technical efficiency (TEi) for each firm can then be calculated as:

$$TE_i = \exp[E(u_i \mid e_i)] \quad (7)$$

so that $0 \leq TE_i \leq 1$.

The empirical model

The translog functional form used to specify the stochastic frontier production function in this study is as follows:

$$LY_t = \alpha_0 + \sum \alpha_i L(X_{it}) + \sum \beta_{ii} L(X_{it})^2 + \sum\sum \beta_{ij} L(X_{it} X_{jt}) + \varepsilon_t \quad (8)$$

where i and j represent the inputs used and t represents driftnet or lampara since the function will be estimated separately for these gear types in West Sumatra. All the input variables in equation 8 are defined and described in table 1 while their measurements are described below.

The West Sumatra fishery can be characterized as multi-species and multi-gear. To sum up the various species caught by the different gears, an index (LANDED) is used. The index attempts to weigh the share of the production value of each major species in the catch. In addition, the vessels used by fishermen consist of various sizes, lengths as well as engine power. Another index (FISH-TECH) is constructed to standardize the various dimensions of the fishing vessels. Similarly, driftnet fishermen use nets of various lengths and mesh sizes. Thus an index (CATCH-POWER) is used to standardize the driftnet. However, the catching power of lampara is determined only by the length of the net because this gear has different mesh sizes on the main part of the net. Besides aggregation and standardization, the index also helps to overcome the problem of multicollinearity. For example, the length, weight, and engine power of fishing vessels are highly correlated.If they are used as separate variables in the model, multicollinearity will arise. The index number combines the effects of these variables into a single variable that helps to reduce multicollinearity.

All indices constructed in this study are geometric indices (Squires 1989). Equations 9, 10 and 11 are used to construct the indices LANDED, FISH-TECH, and CATCH-POWER respectively.

$$LANDED = \prod Y_s^{\%Y_s} \quad (9)$$

where Y_s = the landed value of species s in Indonesian Rupiah.

$\%Y_s$ = the percentage share of the landed value of species s to total landed value of the species by all fishermen.

$\prod$ = the product operator.

$$FISH\text{-}TECH = LB^{\%lb}\ TON^{\%ton}\ HP^{\%hp} \quad (10)$$

where LB = the length of boat in m.

% lb = the percentage share of fishermen's boat in a particular length category of all sampled boats.

TON = the tonnage size of boat in ton.

% ton = the percentage share of fishermen's boat in a particular size category of all sampled boats.

HP = the boat's engine capacity in horse power.

% hp = the percentage share of fishermen's boat in a particular engine capacity category of all sampled boats.

$$CATCH\text{-}POWER\ (driftnet) = MG^{\%mg}\ MESH^{\%mesh} \quad (11a)$$

$$CATCH\text{-}POWER\ (lampara) = MG^{\%mg} \quad (11b)$$

where MG	=	the length of driftnet/lampara gear in m.
% mg	=	the percentage share of the length of driftnet/lampara gear in a particular length category of all sampled driftnets/lamparas.
MESH	=	the mesh size of driftnet in cm.
%mesh	=	the percentage share of the mesh size of driftnet gear in a particular size category of all sampled driftnets.

As shown in table 1, three other variables are included in equation 8. They are FUEL, LABOR, and MGT-ABILITY. FUEL is the total expenditure per boat in Rupiah per year, LABOR is measured as the total fishing man-hours per year, while MGT-ABILITY is measured by the fishing experience of fishermen in years.

Sampling frame and data collection

This study is confined to the coast of West Sumatra in Indonesia. West Sumatra Province has five coastal districts, namely Pesisir Selatan, Padang Pariaman, Agam, Pasaman and Padang. Of the five coastal districts, three were chosen for the study as they contribute a large proportion to the Province's total fish production (information provided by the provincial fishery officials). The selected coastal districts are Padang Pariaman, Padang and Pasaman which contributed 33.35%, 29.88% and 18.82% respectively to the Province's total fish production.

The primary data concerning fishing activities were collected using a structured questionnaire. The data provided information on the characteristics of fishing vessels such as the number, length, gross tonnage, engine horsepower, number and types of fishing gear used, length of fishing gear and mesh size, labor, age and experience of fishermen, and information on production such as total catch, fish prices, fishing revenues and costs.

In this study, only fishermen using powered fishing boats of less than 40 GT and those using lampara and driftnet were included in the sample. The sample was selected based on a proportionate random sampling of about 10% for the lampara and driftnet gears used by fishermen in the study area. Chosen for the sampling were 45 fishermen who use driftnet and 66 who use lampara. However, due to incomplete information provided by 11 lampara fishermen during the survey, they had to be excluded from the analysis and resulted to only 55 observations for the lampara fishermen.

The translog stochastic frontier function is estimated with the maximum likelihood estimation (ML) technique using the LIMDEP statistical program package (Greene 1991). The parameters estimated include β, λ, and σ^2 where $\lambda = (\sigma_u / \sigma_v)$ and $\sigma^2 = (\sigma_u^2 + \sigma_v^2)$.

Table 1. Description of variables used in the empirical model.

Variable Name	Symbol	Description
LANDED	LY	Logarithms of index for landed values of fish per year
FISH-TECH	LX_1	Logarithms of index for fishing technology
FUEL	LX_2	Logarithms of fuel expenditure in Rupiah per year
CATCH-POWER	LX_3	Logarithms of catching power index
LABOR	LX_4	Logarithms of fishing time in man-hours per year
MGT-ABILITY	LX_5	Logarithms of management ability in years of fishing experience

Results and Discussions

The empirical estimates of the stochastic frontier production function for the driftnet and lampara fisheries in West Sumatra are presented in table 2. The log-likelihood values show that the translog function provides good fits for the driftnet and lampara. However, only a number of the estimated coefficients are statistically significant for the two equations. The coefficients for fishing technology (FISH-TECH) for driftnet and catching power (CATCH-POWER) and labor (LABOR) for lampara are significant. More coefficients for the square of the variables and the interaction between variables for driftnet are significant compared to those for the lampara.

The estimated coefficients can be more readily interpreted in the form of elasticities. Output elasticities for individual inputs can be calculated from these coefficients. For example, the output elasticity of fishing technology (FISH-TECH) for driftnet is

$$\partial LY / \partial X_1 = 81.796 + 8.010LX_1 - 5.437LX_2 - 17.096LX_3 - 2.920LX_4 - 2.405LX_5 \quad (12)$$

The output elasticity of FISH-TECH for driftnet is then estimated by substituting all input values at their sample means. The output elasticities of all inputs for driftnet and lampara are presented in table 3.

Table 2. Estimated parameter of the Translog Stochastic Frontier Production Function for driftnet and lampara in West Sumatra.

Variable	Driftnet		Lampara	
	Coefficient	t-ratio	Coefficient	t-ratio
Constant	12.192	0.204	-8.251	-0.283
LX_1 (Fish-TECH)	81.796	2.033*	2.217	0.055
LX_2 (FUEL)	-1.5907	-0.198	-5.138	-0.830
LX_3 (CATCH-POWER)	-41.219	-1.229	4.301	1.520*
LX_4 (LABOR)	-0.057	-0.009	11.068	2.298*
LX_5 (MGT-ABILITY)	-2.450	-0.391	0.678	0.183
$L(X_1X_1)$	8.010	0.712	4.243	0.196
$L(X_2X_2)$	0.035	0.127	0.382	0.958
$L(X_3X_3)$	-1.379	-0.164	-0.106	-0.764
$L(X_4X_4)$	-1.003	-1.327*	0.056	0.138
$L(X_5X_5)$	-0.513	-2.375*	-0.203	-0.949
$L(X_1X_2)$	-5.437	-1.787*	-2.471	-0.721
$L(X_1X_3)$	-17.096	-1.124	2.654	0.860
$L(X_1X_4)$	-2.920	-1.258	3.497	0.888
$L(X_1X_5)$	-2.405	-0.854	-0.931	-0.325
$L(X_2X_3)$	2.975	1.457*	-0.231	-0.552
$L(X_2X_4)$	0.273	0.409	-0.798	-1.227
$L(X_2X_5)$	-0.006	-0.018	0.444	1.118
$L(X_3X_4)$	-0.840	-0.317	-0.110	-0.273
$L(X_3X_5)$	4.044	1.402*	-0.128	-0.614
$L(X_4X_5)$	1.479	2.198*	-0.703	-1.525*
Log likelihood	63.4528		71.9344	
λ	245.89		0.8943	
σ	0.1180		0.0773	
γ	0.1179		0.0344	

* significant at 10% level

Table 3. Output elasticities calculated from table 2 at the mean level of inputs.

Input	Output Elasticities	
	Driftnet	Lampara
LX_1 (Fish-TECH)	46.8323	-13.713
LX_2 (FUEL)	-1.1556	-4.140
LX_3 (CATCH-POWER)	-36.2227	0.529
LX_4 (LABOR)	-1.0637	-0.382
LX_5 (MGT-ABILITY)	-4.1548	0.822
Returns to Scale	4.2355	-16.884

The output elasticities of FISH-TECH are 46.83 and –13.71 for driftnet and lampara respectively. These show that landed value of driftnet increased by 46.83% while that of lampara decreased by 10.91% for every percentage increase in fishing technology. The negative output elasticity for lampara indicates that lampara fishermen might have been using unnecessarily larger boats since FISH-TECH is an index to represent the length, size and horse-power of boats.

The negative output elasticities of FUEL for both driftnet (–1.16) and lampara (-4.14) revealed that too much fuel is being used by these fishermen. These may imply that driftnet and lampara fishermen have to travel to fishing grounds further from shore resulting in larger amount of fuel usage.

The elasticities of CATCH-POWER for driftnet is –36.22 and 0.53 for lampara. The negative elasticity for driftnet indicates that bigger mesh size and longer net have negative effect on the output landed. This could be due to the fact that small pelagics are the dominant species caught by driftnet fishermen and thus bigger mesh size tends to catch less.

Likewise, the negative output elasticities of LABOR for driftnet and lampara indicate that too much labor were being used by these fishermen. The labor input would have to be reduced in order to increase the output level.

The output elasticity of MGT-ABILITY for driftnet is negative while that for lampara is positive. The negative elasticity for driftnet is consistent with that of Tokrisna et al. (1985), that younger and less experienced fishermen appear to be better managers compared to their older and more experienced counterparts. This might be due to the fact that younger fishermen tend to use modern and technologically advanced fishing equipment and techniques compared to those who have been fishing for many years.

The results show increasing returns to scale exists for driftnet fishermen while decreasing returns to scale is shown for lampara fishermen. These imply that the level of fishing effort in the lampara fishery has exceeded the maximum sustainable yield level while the reverse is true for the driftnet fishery. There is still room for improvement in the driftnet fishery but efforts need to be reduced in the lampara fishery.

The statistical significance of λ obtained from the ML estimates indicates the existence of a stochastic frontier function (Schmidt and Lin 1984). As shown in table 2, λ for driftnet is statistically different from zero at 1% significant level, implying that the difference between the observed and the frontier production is dominated by technical inefficiency.

For lampara, the value of λ is 0.89 and it is not statistically significant from zero at the 1% level. This implies that any difference in the production by lampara is attributed solely to symmetric random errors. In other words lampara fishing units currently operating on the frontier, are technically efficient, and except for random disturbances, are receiving maximum output response for the combinations of the bundle of inputs used.

The γ measures total variations in output from the frontier attributable to technical efficiency. The value of γ for driftnet is 0.1179 implying that 11.79% of the discrepancies between the observed and frontier values of output for driftnet is due to technical inefficiencies. Similarly, γ for lampara is 0.0344 which implies that only 3.44% of the differences between the observed and the maximum frontier output is caused by technical inefficiency. The shortfall of realized output from the frontier is primarily due to factors that are within the control of lampara's fishermen.

The technical efficiency ratio, the ratio of actual to potential output, was calculated for each of the 45 driftnet and 55 lampara fishing units. The technical efficiency for each individual driftnet unit ranged from 0.7272 to 0.9989, while that for each lampara unit, the range is from 0.9035 to 0.9829.

Table 4 presents the frequency distribution of these technical efficiency ratios for driftnet and lampara fishing units. The driftnet and lampara units display different characteristics with respect to the spread of technical efficiency across the samples. Approximately 70% of driftnet units achieved more than 90% technical efficiency, while lampara units were all above 90% technical efficiency. This finding supports our earlier assertion that all vessels in the lampara fishery are currently operating approximately on the frontier.

Technical inefficiency can be calculated as $(1 - TE_i)$, where TE_i denotes the technical efficiency of the i^{th} firm. The technical inefficiency measures the degree of failure to produce the maximum output from a given level of input. One per cent technical inefficiency means that the fishing unit could have caught one per cent more fish from the existing level of input. The computed technical inefficiency for driftnet units ranged from 0.0011 to 0.2728, while for the lampara units, it varied between 0.0171 and 0.0965. This means that there exists 0.11 to 27% potential for increasing catch from the driftnet units using

Table 4. Technical efficiency for driftnet and lampara fishery in West Sumatra.

Efficiency indes	Driftnet		Lampara	
	No. of fishing unit	% of fishing unit	No. of fishing unit	% of fishing unit
0.956 – 1.000	23	51.11	37	67.27
0.901 – 0.955	8	17.78	18	32.73
0.856 – 0.900	5	11.11	0	0.0
0.801 – 0.855	5	11.11	0	0.0
0.756 – 0.800	3	6.67	0	0.0
0.701 – 0.755	1	2.22	0	0.0
0.656 – 0.700	0	0.00	0	0.0
0.000 – 0.655	0	0.00	0	0.0
Mean	0.9292	0.9598		
Minimum	0.7272	0.9035		
Maximum	0.9989	0.9829		
Total	45	100.00	55	100.00

the existing levels of input, while the potential increase in catch for the lampara units ranged between 1.71 and 9.65%. Therefore, higher capacity for expansion exists in the driftnet catch by adopting the technology of the highly experienced fishermen and through optimal resource allocation. The prospect for expansion for the lampara units is however, rather limited as they are currently producing near the maximum.

The results of this analysis also show that on the average, there is 7.08% technical inefficiency for the driftnet units and 4.02% for the lampara units (Table 4). This indicates that actual driftnet catch is 7.08% less than the maximum catch achievable from the existing levels of input used. On the other hand, the maximum catch that can be achieved by the lampara units from current levels of input used is 4.02% higher than the actual catch. This indicates that the opportunities to increase the production can be done through "new" and "effective" technology. This is consistent with what was proposed by Battese (1992), that is, very high levels of technical efficiencies indicated that increasing production would require new innovations or a high level of technology to be introduced.

Conclusions

The lampara fishing units in West Sumatra have high technical efficiency, while 70% of the driftnet units achieved 90% technical efficiency. The findings suggest that there is more room for catch expansion in the driftnet fishery by adopting technology of the highly experienced fishermen and through optimal resource allocation compared to the lampara fishery. For driftnet fishery, catch can be increased through technological improvement. As an additional step toward raising the standards of living of driftnet fishermen, policies should also be directed to provide better infrastructures such as an efficient marketing system. Since lampara fishery operate near shore, the best alternative to increase catch is to reduce fishing effort. In doing so it is hoped that the catch per unit of lampara will increase and at the same time improve the fishermen's earnings.

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