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Technical efficiency evaluation of tuna fishing biology using stochastic frontier production function

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Abstract

Many studies have been conducted and developed about the allocation of tuna's resource and productivity. This research is done to analyze the best stochastic frontier production function model and evaluate technical efficiency of tuna fishing based on the kind of armada using frontier production function approach. This research was conducted in Sendang Biru, Malang District, Indonesia, involving 54 boats and 25 *payang* armadas. Research data was obtained from the related agency. Translog and Cobb-Douglas stochastic frontier production functions were then compared to obtain the best function. Technical efficiency was analyzed statistically based on the determined parameters. The result shows that stochastic frontier production function in Cobb-Douglas is the most accurate function for evaluating tuna fishing's technical efficiency. Tuna fishing's technical efficiency at boat armada is higher than *payang* armada based on several factors. Based on this research, it's acknowledged that main things influencing the technical efficiency are ship captain's experience and investment.

Keywords: fish biology, Cobb-Douglas, stochastic frontier, technical efficiency, translog, tuna fishing

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INTRODUCTION

Tuna is one of the most important commodity in the sea, which 68.03% of it come from Indonesian waters, those are Indian and Western Pacific Ocean (Sitorus 2007). The tuna potency that has been developed are *madidihang* (yellowfin tuna), big-eye tuna, and southern bluefin tuna. Several factors influencing tuna fishing production are input factor using by the fisherman and the fisherman's ability to use that input factor. Empirically most of the tuna fisherman are aprice taker, so theoretically the fisherman's orientation should beguided to increase efficiency (Tajerin and Noor 2005). Research of tuna's resource allocation and fishing productivity has been conducted by the experts for a long time. However, until this day there are still many result differences among the experts. Selected ships show that the difference in size, age, and fishing target. Many factors influence tuna's efficiency level and fishing productivity (Çanakçı et al. 2018, Ece et al. 2013).

Efficiency level shows how much the output produced per certain input unit. The reality is the fisherman don't always achieve the technical efficiency level as expected. Whereas a inefficient business is if it fails to achieve maximum production by using a number of existing inputs (Dalam Utama, 2003, Farrell 1957). Although they use same tools, technology, and resources, and even on the same season and in the same spot, the variety always come up. Factors that can influence such as either the fisherman's or the ship captain's skill, ability, and experience level so the tuna fishing can be conducted optimally. The managerial capability will be reflected by the output when obtaining the fishing result. Generally, socio-economic factors of farmers, the characteristics of farming, demography, physical environment become the source of the difference technical inefficiency (Kebede 2001). If the production obtained from a similar ecosystem/region close to the maximum potential, then it can be declared that fisherman has been conducted tuna fishing with high technical efficiency.

In general, the research about technical efficiency is conducted using stochastic frontier production function (Alavi 2013, Kheiry et al. 2013, Pascoe and Tingley 2003). The research conducted by Kirkley, Squires, and Straind, (1995) shows that technical efficiency test is produced by predicting a frontier production stochastic. Renewable resources exploitation shows integral with the stochastic. Weather condition, biological abundance, and availability become extreme variables and the ship captain must often make a quick adjustment to respond

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resources and weather condition shift. Meanwhile, in Indonesia the fishing's production function prediction use average approach, so it can't see the technical efficiency to every fisherman. Moreover, this research aims to analyze the best stochastic frontier production function and evaluate fishing technical efficiency based on the kind of armada using frontier production function approach to the fisherman in Malang, Indonesia.

MATERIALS AND METHODS

Place of Research

This research was conducted in Sendang Biru, Malang District. The research location is one of the tuna central production in Province of East Java. A number of research samples were 54 boat armadas and 25 *payang* armadas. Those 79 armadas actively conducted tuna fishing activity in the research location.

Data Gathering

Collecting data of this result was conducted by two steps. The first step was collecting data of tuna fishing fisherman in the research location. The second step was data gathering. The gathered data included primary and secondary data. Primary data was cross-section data which gathered from the researched fisherman along the year 2009 covering peak, average, and famine season. Primary data gathering was conducted by interview based on prepared questionnaire lists, while the secondary data was gathered from there lated agency.

Data Analysis

The analysis technique used in this research was stochastic frontier production function analysis. The form of stochastic frontier production function will be chosen from the best model from two kinds of Translog and Cobb-Douglas frontier production function forms.

Cobb-Douglas

$$\ln YPF_1 = \alpha + \beta_1 \ln AT_{1,i} + \beta_2 \ln KK_{2,i} + \beta_3 \ln HOKM + \beta_4 \ln PM_{3,i} + \beta 5 \ln PES_{4,} + \beta_6 \ln BB_{5,i} + V_t - U_t$$

Translog

$$YPF_i = \alpha + \beta_1 \ln AT + \beta_2 \ln KK + \beta_3 \ln HOKM + \beta_4 \ln PM + \beta_5 \ln PES + \beta_6 \ln BB + \beta_8 (\ln AT)^2 + \beta_9 (\ln KK)^2 + \beta_{10} (\ln HOKM)^2 + \beta_{11} (\ln PM)^2 + \beta_{12} (\ln PES)^2 + \beta_{13} (\ln BB)^2 + V_t - U_t$$

Note: YPF_i=Number i fisherman's production, v_i=Fisherman's uncontrollable random error, u_i=Number i fisherman's technical inefficiency level, AT=Fishing tool, KK=Boat power, $HOKM$=The day people work at sea, PM=Food supply, PES=Ice supply, BB=Fuel.

First tuna fishing's technical efficiency will be predicted by the equation formulated by Battese, G.E. and Coelli (1988) as follows:

$$TE_i = \exp(-u_i)$$

Where the efficiency can be predicted by the equation:

$$E[\exp(-u_i \mathrm{I} E_i)] = \exp[\mu_i^* + 0.5\sigma^{*2}] x \left[\frac{\phi(\frac{\mu_i^*}{\sigma^*} - \sigma^*)}{\phi(\frac{\mu_i^*}{\sigma^*})} \right]$$

Where $E_i = v_i - u_i = \frac{\sigma_v^2 - \sigma_u^2}{\sigma_v^2 - \sigma_u^2}$ and $\sigma^{*2} = \frac{\sigma_v^2 - \sigma_u^2}{\sigma_v^2 - \sigma_u^2}$ also representation from normal distribution function for random variable.

In order to test the hypothesis that the fisherman had conducted fishing efficiently, it was conducted by test using Likelihood Ratio Test as follows:

$$H_0: \sigma_u^2 = 0$$
$$H_1: \sigma_u^2 = 1$$

This hypothesis stated that σ_u^2 =0 means $\gamma = \frac{\sigma_u}{\sigma_v}$ and ncdf = 0.

LR test equation is:

$$LR = -2[\ln(L_r) - -\ln(L_u)]$$

Furthermore, this LR value was compared with the critical value of χ_1^2, and the software used to predict stochastic frontier production function was Frontier by TIM Coelli. Meanwhile, in order to analyze factors determining tuna fisherman's technical efficiency level, it was formulated econometrically as follows:

$$Z_1 = \alpha + \beta_1 D_1 + \beta_2 D2 + \beta_3 D_3 + \beta_4 D_4 + \beta_5 D_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + V_t - U_t$$

Where: Z=Technical efficiency, D_1=KUD (Village Unit Cooperative) membership, D_2=Owner's tribe, D_3=Ship captain's tribe, D_4=Season, D_5=Ship captain's status, X_6=Ship captain's experience, X_7=Investment, X_8=Ship captain's educational background, α, β= Estimated parameter

This equation model then was estimated by OLS (Ordinary Least Squares) method. OLS method was used because it has a very interesting statistical feature that made it become one of the strongest and most popular regression analysis method (Aşan et al. 2017, Neubauer et al. 2004). This method's power lies especially at its accuracy to predict population using samples, which means of the smallest square estimation of the data, its regression line can be fitted easily.

RESULTS AND DISCUSSION

Frontier Production Function and Tuna Fishing's Technical Efficiency Distribution Prediction of tuna fishing's frontier production function which differentiated on the kind of boat and *payang* armada. That production function prediction based on the armada is very helpful to find technical efficiency based on the kind of armada. The difference between frontier production function and correlation among fishing work time with tuna fishing result based on the kind of armada is shown in **Table 1** and **Fig. 1**.

The best of tuna fishing's frontier production function either at the boat or *payang* armada is in Cobb-Douglas form. This is shown by λ-value criteria that positive and bigger than zero and also significant which measures if there is technical inefficiency influence, high γ-value up

Table 1. Frontier production function of tuna fishing

Variable	Variable Code	Coefficient	
		Boat	Payang
Intercept	beta 0	3.75 **)	3.47 **)
Dummy peak season	beta 1	0.26*)	0.09
Dummy average season	beta 2	0.23**)	0.03
Fishing work day	beta 3	0.89**)	0.48**)
Fuel	beta 4	0.01	0.29**)
Food supply	beta 5	0.02	0.05
Ice supply	beta 6	0.17*)	0.06
	sigma-squared	0.25**)	0.08**)
	Gamma	0.91**)	0.87**)

Note: *) real at test interval 5 %; **) real at test interval 1 %

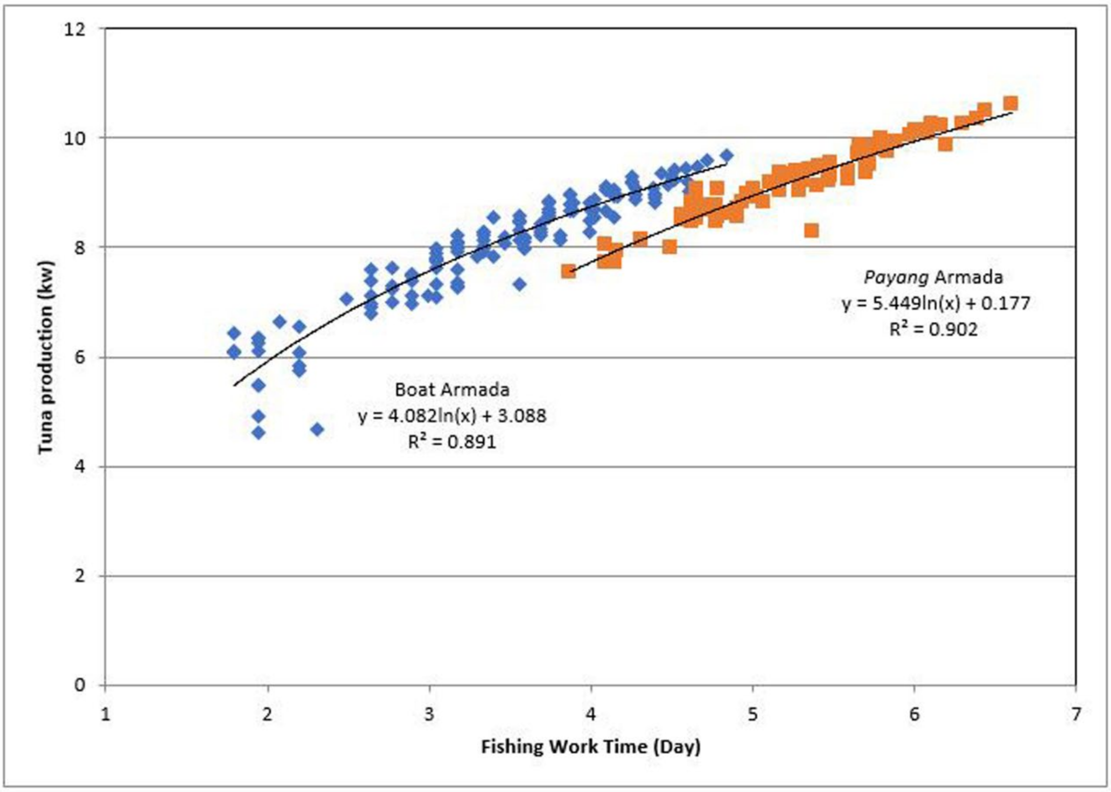

Fig. 1. Correlation between fishing work time and tuna fishing result based on the kind of armada

Table 2. Tuna fishing's technical efficiency source of boat and *payang* armada

Variable	Variable Code	Boat	*Payang*
Constant	(Constant)	-0.145	0.399**)
Dummy KUD	D1	0.04°)	0.103**)
Dummy Bugis tribe	D2	0.048 *)	-0.022
Dummy Maduranese tribe	D3	0.041	0.031
Dummy Bugis ship captain	D4	-0.041	-0.002
Dummy Maduranese ship captain	D5	0.049	-0.017
Dummy peak season	D6	0.017	-0.008
Dummy average season	D7	0.006	0,000
Ship captain's experience	PGLM	0.024**)	0.007**)
Investment	INV	0.002**)	0.001**)
Ship captain's educational background	PDDKN	0.013	-0.001

Note: o) real at test interval 10 %; *) significantat test interval 5 %; **) significant at test interval 1 %

to 90 percent showing a variation of error composite value is caused by technical inefficiency component, and the parameter value is suitable with economical and statistical criteria.

Tuna fishing's frontier production is influenced by how many days the fisherman work either in the boat or *payang* armada. This research result also shows that more experience causes tuna fishing result increase either in the boat or *payang* armada. However, fishing production at the boat armada is higher than *payang* one. The significant difference lies in season variable influence, which at the boat armada have real influence, whereas at the *payang* one does not. As explained before, this is caused by tuna fishing at the boat armada is the main business, while *payang* one isn't the main business so the season factor isn't significant (**Table 2**).

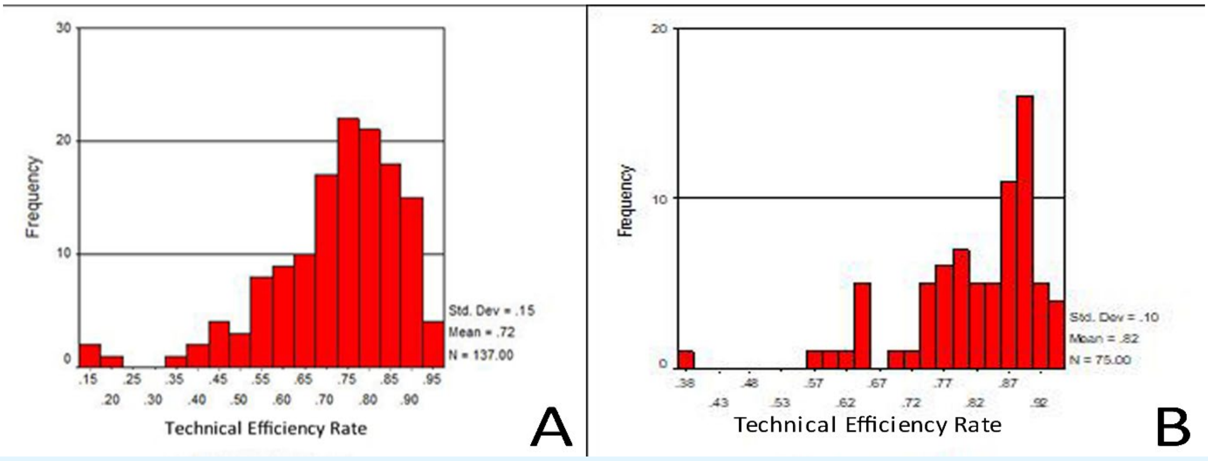

Fig. 2. Technical efficiency distribution of tuna fishing from boat armada (a) and *payang* armada (b)

Boat and *payang* armada's tuna fishing's technical efficiency result at every respondent shows that technical efficiency level distribution of boat armada is relatively high, that is 72% in average, whereas the variation is 15%. Looking from the technical efficiency interval, tuna fishing with boat armada are distributed from minimum efficiency of 0.13 to maximum of 0.95. Meanwhile, tuna fishing's technical efficiency with *payang* is 82% in average and 10% of the variation. Looking from the technical efficiency interval, tuna fishing with *payang* armada are distributed from the minimum efficiency level of 0.38 to the highest of 0.92 (**Fig. 2**).

Technical efficiency is predicted simultaneously with technical efficiency determinant at the ship level, and also describes output elasticity and turn over. Gross revenue per trip, fishing business, fishing tool picking, fishing duration (month), and ship equipment's data are analyzed by stochastic translog production frontier, including a model of ship's technical specific inefficiency. Technical inefficiency influence is seemed very significant in order to explain level and variation of ship revenue. The average efficiency for the ship samples is predicted 66% (Battese and Coelli 1995).

According to the analysis result conducted before, it is obtained the fact that technical efficiency sources of tuna fishing either in the boat or *payang* armada are relatively almost equal. Main factors that can increase technical efficiency are the membership of KUD (Village Unit Cooperation) and the ship captain's experience, but the technical efficiency of boat armada will be higher if the ship-owner is from Bugis tribe. The ship owner often becomes ship captain because the tribe's work ethic is identical by the fisherman with braveness and high sailing skill. Further, according to Sharma and Leung (1999), the boat that independently operated by ship owners tend to be more efficient than boat operated by hiring ship captain. Leadership ability also influences fishing result's productivity level very much. Kirkley et al. (2004) stated that the leadership ability is a very important thing to having by a ship captain in order to increase fishing output's productivity and level. However, there are some reasons that make the lack of research to know the indicator of "good leader". This is caused by the difficulty to measure the leadership ability directly, and lack of several important data needed to test the ability characteristic. While according to the research of Waridin (2006), more human resources will ease and fasten either to rise or spread the net so the fishing output will be more at the same time. Fuel is a very important production factor because without fuel the ship can't be operated and determines how far the ship can reach the fishing ground. More fuel carried, more freedom for the fisherman to reach desired fishing ground especially at the high-populated fish region. The Large size of fishing tool *cantrang* enables fishing area scope to be larger so it is hoped to obtain more output than a smaller *cantrang* fishing tool. However, the increasing of the ship's human resources and larger fishing ground scope make the work at the sea need more provision.

Correlation of Ship Captain's Experience and Investment to Tuna Fishing's Technical Efficiency. This research result shows that the ship captain's experience and investment give positive influence to technical efficiency. Based on the parameter result obtained, it can be arranged the difference of technical efficiency between the boat and *payang* armada related with ship captain's experience and investment.

Correlation between technical efficiency level with the ship captain's experience and investment at the boat and *payang* armada have a few technical efficiency differences. The difference is shown by the difference of technical efficiency line slope, which at the boat armada values 0.024, while at the *payang* one is 0.007. This shows that the ship captain's experience at the boat armada is more responsive than at the *payang* armada. There is a positive correlation between technical efficiency with the ship captain's educational background and experience (Kirkley et al. 2004).

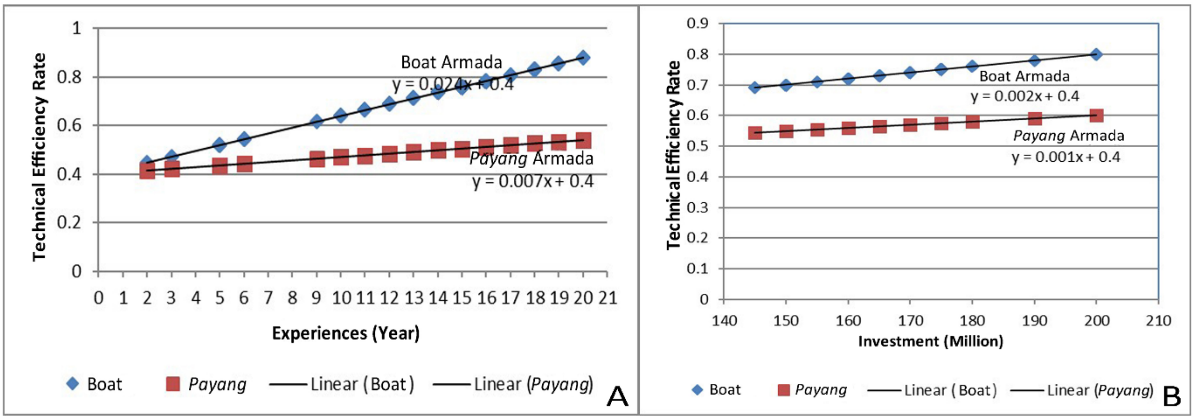

Fig. 3. Correlation of tuna fishing's technical efficiency with the ship captain's experiences (a) and investment (b)

The ship owner's investment reflects the fisherman's economic power factor. Moreover, if the economic power is big, then the technology, maintenance, and operational cost adjustments will be very easy to do. Correlation between investment to the tuna fishing's technical efficiency is relatively similar with the ship captain's experience influence. The result shows that at the boat armada the investment influence is higher than at the *payang* one with the value of 0.002 and 0.001 (**Fig. 3**).

Based on this fact, it is acknowledged that not all of the fisherman have the high economic ability, so in order to increase tuna fishing output credit and investment role to the fisherman are still relevant to implementing. According to Waridin (2006), other factors influencing technical efficiency related with the investment are fuel, ship, and provision. Those factors give real influence to the technical efficiency. Precise allocation of production factors combination can increase the efficiency. Efficient fishing tool using is hoped can increase fishing production that finally can increase fisherman's revenue. Fishing tool's efficiency is measured by stochastic frontier production analysis, which looked from technical and price (locative) efficiency. Achieving those efficiencies means also achieving economic efficiency. Fishing tool efficiency can increase fishing tool production that finally will increase the fisherman's revenue.

This research can be concluded that stochastic frontier production function in Cobb-Douglas form is the most accurate production function to evaluate tuna fishing's technical efficiency. Tuna fishing's technical efficiency at the boat armada is higher than the *payang* armada viewed according to several factors. Main things influencing technical efficiency are the ship captain's experience and investment.

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