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Production Efficiency Analysis of Oil Palm Plantations: Stochastic Frontier Approach

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ABSTRACT

Palm oil is a commodity in the plantation sector that has an important role in the economy of North Sumatra Province. The oil palm plantation sector is one of the main sources of income for the people in South Labuhan Batu regency. The productivity of smallholder oil palm plantations is relatively lower when compared to the productivity of oil palm managed by large plantations. This study aims to determine the factors that influence the production and technical inefficiency of oil palm production. The research location is in South Labuhanbatu Regency, North Sumatra Province, which was carried out in 2020. Sampling was carried out using a purposive method, namely as many as 45 oil palm farmer households. The approach used is the stochastic frontier production function. Maximum likelihood estimation method used. The results of the analysis show that the area and the number of workers significantly affect the production of oil palm farmers. The technical inefficiency factor is caused by the age of the farmer, and the number of household members involved in oil palm farming. To measure the use of all resources can be used the concept of return to scale. The sum of all the elasticity responses to the use of all inputs estimated using the maximum likelihood method of the stochastic production function is 1.09, which indicates that an increase in all available inputs leads to a greater increase in farmers' income. Government support is needed in the form of farming practice improvement and access to capital to achieve production at the frontier point with an opportunity of 10.93 %.

Keywords: Increasing return to scale, palm oil, stochastic frontier, technical efficiency

INTRODUCTION

The agricultural sector has a fairly important role in economic activity in Indonesia; this can be seen from its contribution to the Gross Domestic Product (GDP), which is quite large, namely around 13.7 percent in 2020 or posits in the second position only after the Manufacturing Industry sector infesting in 19.88 percent. One of the sub-sectors that has quite a large potential is the plantation sub-sector. The contribution of the sub-sector in 2020 is 3.63 percent of total GDP and 26.50 percent of the Agriculture, Forestry and Fisheries sector or is in first place in this sector[1]. The role of the agricultural sector is also illustrated through a real contribution in the capital formation, provision of food, industrial raw materials, absorbing labor, a source of income, and preserving the environment through environmentally friendly farming practices.

In Indonesia, the distribution of palm oil production (POP) is spread across several provinces, for instance, North Sumatra Province (NSP) contributes 11.96% (5.78 million tonnes/year) to national production (which was 48,297 million tonnes/year). The NSP becomes the third largest national contributor. The plantation sector in NSP is one of the strategic sub-sectors which has economically, ecologically and socio-culturally important role in the development of this province . Plantation crops such as palm oil and cocoa have faster growth and are highly competitive[2].

On the basis of number of districts in NSP, South Labuhan Batu (SLB) regency is the third largest contributor after Asahan and Langkat regencies[1]. This condition also justifies that in the SLB, palm oil is an important sector for the people here, and becomes the main source of livelihood for smallholders. In Indonesia in 2020 the area of oil palm plantations (OPPs), specifically for annual crops, is 16.93 million hectares, of which there are around 6.01 million hectares (35.45%) of the OPPs; all this shows that oil palm smallholders (OPS) have an important role for the national and provincial economy. The OPPs in NSP with an area of 1,126,471,916.3 (53%), when compared to large plantations, such as PTPN, PBSN and PBSA having 998,946.79 (47%) area, are still lagging from their production contribution. The OPS' main problems in NSP are related to low production, fluctuating selling prices, weak planter institutions and low added value, and commodity competitiveness due to low cost efficiency and low quality[3].

The average productivity of OPS is around 16 tons of FFB/ha/year[4]. According to Corley, this productivity is still far below the optimal production which can be achieved at 30 tons of FFB/ha/year[5]. Boer et al. explained that there is a relatively high productivity gap between plantations owned by OPS and by owners of large private plantations, ranging from 41% -64% of plantation productivity which reaches 7-20 tonnes of FFB/ha/year[6]. Independent small farmers (ISFs) are less productive than small farmers who are members of partnerships with core companies. The ISFs are defined as smallholders who finance and manage their own plantations, which, in their findings, have lower oil palm productivity due to a lack of capital, knowledge and facilities.

Production factors that are considered to have an effect on the output of fresh fruit bunches (FFB) produced are concerned to fertilizer, land, labor, principal amount, and pesticides. The fertilizer and pesticide doses, the number of labors and stems, and the land area width can be categorized as production inputs, while the age of the plant and the class of land cannot be categorized as production inputs but still affect the yield of FFB[7],[8],[9],[10]. To increase productivity and the POP, it is necessary to pay attention to the level of production efficiency which is reflected in the performance and quality of production factors used by farmers, such as labors, land area, fertilizers, pesticides and farmers' socio-economic factors. Study regarding to the level of production efficiency of ISFs is important to find out how big the farmers' opportunity to increase the potentials for oil palm production and to escalate the OPS' income.

LITERATURE REVIEW

To increase productivity, an optimal level of efficiency is required. To achieve economic efficiency, farmers should try to achieve maximum output from a certain set of inputs (technical efficiency) and produce output with an optimal combination of inputs at a certain price level (allocative efficiency). Referring to the Cobb-Douglass production concept, two production factors are assumed in (1).

$q = f(x, y)$ … (1)

wherein q is the amount of production, and x and y variables are production factors. Maximum production is achieved on the isoquant curve tangent to the isocost curve, which is at point A (see Fig. 2). Efficiency can be technical and allocative; the first is related to the ability to obtain maximum output by certain inputs, and the latter is concerned with the ability to use the optimal proportion of inputs according to the price and production technology it has. When the two merge, economic efficiency can be achieved[11],[12].

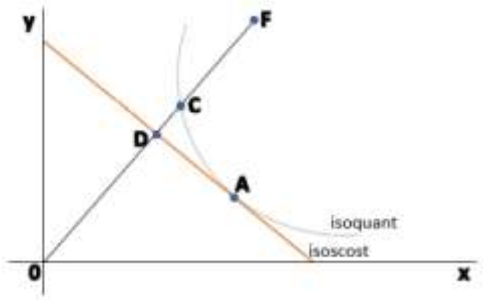

Figure 2. Isoquant, Isocost and Technical Efficiency Curves
Source: adapted from Coelli et al. (2005)

Efficiency measurement is directed to gage the distance from the observed data point to its frontier, or technical efficiency is expressed by how far the farming operation deviates from the production function of the frontier at a certain technological level. The difference in the distance between points F and B (see Fig. 2) indicates a technical inefficiency, which is the amount of input usage that can be reduced without lowering the amount of output obtained. This input reduction is usually percentaged by the FA/0A ratio to achieve technically efficient production. Technical efficiency can be calculated by 0D/0A[11].

Production factors affecting the output of FFB are fertilizer, land, labor, number of stems, and pesticides. The fertilizer and pesticide doses, the amount of labors, the land area width, and the amount of principal can be categorized as production inputs, while the age of the plants and the class of land cannot be categorized as production inputs but still affect the FFB yield. To increase productivity and POP, it is necessary to pay attention to the level of production efficiency which is reflected in the performance and quality of production factors used by farmers, such as labor, land area, fertilizers, pesticides and farmers' socio-economic factors. Hence, it is important to study in more depth regarding the level of production efficiency of ISFs, and to find out how big the opportunity for them to increase the POP is to increase the OPS' income.

MATERIALS AND METHOD

The SLB regency was chosen as the research location (lab/studio/field) which was determined purposively in accordance with the research objectives. The type of data was qualitative and quantitative taken from primary and secondary data; the primary data were obtained from in-depth interviews using questionnaires as survey guidelines, given to farmers, and were carried out from June to December 2020. Meanwhile, secondary data were gathered from relevant agencies, especially from the Central Bureau of Statistics and other related agencies and institutions. The number of respondents were 45 and data presentation involved descriptive statistics in the form of tabulations and cross-tabulations.

The measurement of efficiency in this research utilized stochastic frontier analysis (SFA) available from three articles[13],[14],[15]. The three consisted of almost similar ideas one another, that is, they discussed the error structure formed in the production frontier modeling. The model was outlined in the form of the following equation in (2)[11].

$q = f(x, \beta)\exp(v - u)$ … (2)

In the stochastic frontier-Cobb-Douglas production model, equation (2) can be rewritten as (3):

$\text{Ln } q = \beta 0 + \beta i \text{ Ln } xi + vi - ui$ … (3)

wherein q is the output, x is the input, and βi refers to i-parameter which would be estimated. The error component v is a form of statistical noise accommodation with the assumption that it is identical and normally distributed as $N(0, \sigma_v^2)$. The error component u is a form of accommodation for technical inefficiency with the assumption that $U \geq 0$ and normally distributed as $N_+(0, \sigma_u^2)$. The notation N_+ indicates that for the half-normal and truncated normal distribution models, the error distribution is concentrated at half the interval $(0, \infty)$; it is also assumed that v is distributed independently of u. The operational model of the stochastic frontier production model in this study is written as (4):

$\text{Ln } q_i = \beta_0 + \beta_1 \ln x_1 + \beta_2 \ln x_2 + \beta_3 \ln x_3 + \beta_4 \ln x_4 + \beta_5 \ln x_5 + v_i - u_i$ … (4)

wherein
qi = palm oil production (kg)
x1 = land area (ha)
x2 = number of workers (HOK)
x3 = number of NPK (kg)
x4 = amount of ZA fertilizer (kg)
x5 = amount of pesticides (liters)
β_i = parameter to be estimated where i = 1,2,3, …,n
The *-ui* factor is a technical inefficiency factor that is calculated from the farmer's age, dummy status of the farmer's membership in the institution, level of education, the experience and number of members of the farmer's household. The *u* factor is specified in (5).

$u_i = \alpha_0 + \alpha_1 z_1 + \alpha_2 z_2 + \alpha_3 z_3 + \alpha_4 z_4 + \alpha_5 z_5 + w_i$ … (5)

wherein:
z_1 = age of oil palm plant (years)
z_2 = level of education (years)
z_3 = experience in farming (years)
z_4 = number of farmer household members (people)
z_5 = farmer's age (years)
α_i = parameter to be estimated, where i = 1,2,3,…,n
w_i = component error term

The specification of a half normal distribution according to Aigner et al. produced a density function for the ε which has a solution using the maximum likelihood estimation method[14]. Concerning the half-normal model, the specification of the density error function according to Kumbhakar et al. (2017) are shown in (6):

$$f(\varepsilon) = \frac{2}{\sigma}\phi\left(\frac{\varepsilon}{\sigma}\right)\Phi\left(-\frac{\varepsilon\lambda}{\sigma}\right) \ldots (6)$$

wherein $\phi(.)$ is the standard normal probability density function, $\Phi(.)$ refers to the standard normal cumulative distribution function, with the basic parameters are indicated in (7):

$$\sigma = \sqrt{\sigma_u^2 + \sigma_v^2} \text{ dan } \lambda = \frac{\sigma_u}{\sigma_v} \ldots (7)$$

The parameter λ is generally interpreted as the portion of variation of ε due to inefficiency. If the value $\lambda > 0$, the production is dominated by technical inefficiencies. If $\lambda = 0$ means there is no effect of technical inefficiency and all deviation from the frontier is due to noise. Coelli argued that the Wald's *t-test* for $\lambda = 0$ and versus $\lambda > 0$ is not suitable for testing the existence of a frontier[16]. Coelli and Battese and Corra recommended a one-sided likelihood ratio test as shown in the followings[16,15]:

$H_0 : \gamma = 0$ (shows no technical inefficiency)
$H_1 : \gamma > 0$ (indicates technical inefficiency)
wherein

$$\gamma = \frac{\sigma_u^2}{\sigma_v^2 + \sigma_u^2} \ldots (8)$$

Regarding the value $0 < \gamma < 1$, if $\gamma = 0$ indicates that the deviation from the frontier is entirely caused by noise; in other words, there is no technical inefficiency in oil palm farming or technical efficiency has been achieved. Meanwhile, if $\gamma > 0$ denotes that all deviations are caused by technical inefficiencies; in other words, oil palm farming did not reach technical efficiency. By the MLE estimation method and by assuming that the distribution of ε is half normal, and to measure the technical efficiency of farmers, formula of Jondrow et al. is used as written in (9)[17].

$$TE_i = \exp\{-E(u_i|\varepsilon_i)\} \ldots (9)$$

wherein

$$E(u_i|\varepsilon_i) = -\mu_{*i} + \sigma_*\left[\frac{\phi\left(\frac{\mu_{*i}}{\sigma_*}\right)}{1-\Phi\left(\frac{-\mu_{*i}}{\sigma_*}\right)}\right] = \sigma_*\left[\frac{\phi\left(\frac{\varepsilon_i\lambda}{\sigma}\right)}{1-\Phi\left(\frac{\varepsilon_i\lambda}{\sigma}\right)} - \left(\frac{\varepsilon_i\lambda}{\sigma}\right)\right]$$

$$\mu_{*i} = \frac{-\varepsilon_i\,\sigma_u^2}{\sigma^2} \quad \text{and} \quad \sigma_*^2 = \frac{\sigma_v^2\,\sigma_u^2}{\sigma^2}$$

To produce the technical efficiency version of Jondrow et al., software SAS@9.4 is applied by setting the TE2 option in the OUTPUT statement in the HPQLIM procedure[17].

RESULTS AND DISCUSSION

A summary of the results of the estimation using the maximum likelihood method of the Cobb-Douglass translog production function model is shown in Table 1 in which a sigma value of 0.1109 (σ=0.1109) is the standard deviation error, which implies that the residual factor is 11.09 %. While the lambda value (λ) is $\lambda = \frac{\sigma_u}{\sigma_v} = 5{,}0733$, this indicates that the production process is not on the frontier, but on the farmer's production of oil palm which is technically inefficient, or the proportion of variation ε is due to inefficiency factors while the γ value is shown in (10).

$$\gamma \text{ value} = \frac{\sigma_u^2}{\sigma_v^2+\sigma_u^2} = \frac{0,0215}{(0,0215+0,1089)} = 0,1647 \ldots (10)$$

and the formula exhibits that there is technical inefficiency, in the sense that the OPS are still not technically efficient. The value of γ = 0.1647 indicates that there is 16.47% residual variation (u_i) in the model which comes from inefficiency and the rest is due to random error in measurement (v_i). If γ is close to zero, then all error terms come from noise (v_i) such as the influence of weather and other factors outside the model. Technical efficiency requires that the use of inputs proportionally (fewer) produces the same output[18],[19].

Tabel 1. Summary of the Stochastic Frontier Estimation Method

Model Fit Summary	
Number of endogenous variables	1
Endogenous variable	l_q
Number of observations	45
Log likelihood	60,04144
Maximum absolute gradient	0,00004
Number of iterations	33
Optimization method	Quasi-Newton
AIC	-100,0829
Schwarz criterion	-82,0163
Sigma	0,11099
Lambda	5,07339

Table 2 shows that the variable of planted area has a positive effect on oil palm production at the confidence level of 80%; however, the production response to the changes in land area is inelastic because the smallholding area of 10,525.97 hectares is still dominated by dry land (around 8,127 hectares). If sufficient water is available, oil palm may produce up to 28 tonnes/ha/year of FFB in the Southeast Asia region. For every 100 mm of water shortage, oil palm loses yields of around 2.88 tons/ha or around 10%, even if other plantation management practices are applied properly.

Tabel 2. Parameter Estimation Results with the Stochastic Frontier Model

Parameter Estimates						
Parameter	**DF**	**Estimate**	**Standard** Error	**t Value**	**Approx** Pr > |t|	**Label**
β_0	1	8,7597	0,4217	20,77	<,0001	Intercept
β_1	1	0,3411	0,2661	1,28	0,1999	Planted area
β_2	1	0,2369	0,1125	2,11	0,0351	Total manpower
β_3	1	0,0026	0,0028	0,92	0,3584	Total use of NPK fertilizer
β_4	1	0,0071	0,0036	1,96	0,0502	Total use of urea fertilizer
β_5	1	0,5029	0,2865	1,76	0,0792	Total use of herbicide
α_1	1	-0,0816	0,2598	-0,31	0,7535	Plant age
α_2	1	0,1014	0,4124	0,25	0,8059	Farmer's experience
α_3	1	-0,3483	0,3845	-0,91	0,3649	Educational level
α_4	1	0,0900	0,0758	1,19	0,2350	Household members
α_5	1	0,2066	0,3678	0,56	0,5743	Age of the farmer
_Sigma v	1	0,0584	0,0376	1,55	0,1205	Stochastic error component
_Sigma u	1	0,5262	0,0675	7,80	<,0001	Technical inefficiency error component

Source: Primary data, 2021 (processed by SAS@9.4)

Total use of labor has a positive effect on POP and is statistically significant at the 5% confidence level, although the response to changes in production and in the number of workers is inelastic. This indicates that a one percent increase in the use of total labor, ceteris paribus would increase POP by 0.23 percent. The amount of NPK use has a positive effect on increasing POP, although statistically it is not significantly different from zero. The response of changes in production to changes in the amount of NPK usage is inelastic. According to Kasno and Anggria, fertilizer is a very important factor of production, where its application in oil palm nurseries needs to consider the soil used as a medium[8]. Excessive or insufficient fertilization causes the growth of oil palm to be not optimal. The application of NPK fertilizer can increase the growth of oil palm plants, especially for immature plants.

The amount of urea fertilizer use has a significant positive effect on an increase of farmers' POP, although the response to changes in production and in the amount of urea fertilizer used is inelastic. This means that an increase in the use of one percent of urea fertilizer, ceteris paribus would increase POP by less than 1 percent. The balanced use of urea and NPK fertilizers proportionally increases the production of oil palm smallholders. The same findings were also carried out by Nasution and Atmaja, where the use of urea fertilizer had a positive and significant effect on POP at PT. Nusantara IV Plantation located in the Adolina Unit[20].

The amount of herbicide use (round-up and gramoxone) has a positive impact to increase POP and is significant at the 90% level of confidence because the age of the oil palm plants is still an average of 8 years, which can cause a lot of weeds to grow around the crop disks and so relative weed control using herbicides is still necessary.

The sum of all the elasticities of the response to the use of all inputs estimated using the maximum likelihood method from the translog of the stochastic production function is 1.09, indicating that a proportional increase in all available inputs would lead to a greater increase in farmer income. This also indicates how much the farmer's business can increase the returns to scale. These findings are in line with Puruhito et al., where OPS are in a state of increasing return to scale (IRS), even though the estimation technique is not the maximum likelihood, and the Cobb-Douglass functions but transforms in logarithmic form[9]. This result is also in line with Ridha for OPS' conditions in East Aceh regency are in IRS[10].

One of the factors that can reduce technical inefficiency is the age of the plant. The lowest age of OPP managed by OPS is 5 years, and the highest is 11 and the average age of OPP is 8. Increasing the age of plants to a certain point can increase production efficiency and farmers' productivity. This finding is in line with Hafif, et al. stating that the OPP's productivity likely goes up in line with an increase of plant ages, as well as an increase use of organic fertilizers for mature plants and NPK fertilizers for immature ones[7]. Another factor that can reduce technical production inefficiency is the farmers' education level, although it is not statistically significant. The coefficient of the parameter for the level of education is -0.3483, indicating that any increase in formal education reduces technical inefficiencies by 0.34 %.

Social factors that can increase inefficiency in oil palm farming are related to farmers' experience, to number of family members involved in oil palm farming and to farmers' age. In this case, it is quite interesting that the farmers' experience has not been able to reduce technical inefficiencies, including the number of family members. Family workers are unable to reduce technical inefficiencies because they do not have good knowledge about oil palm business management. The *age* factor of the farmer would also cause inefficiency in oil palm farming. The coefficient of the age variable parameter is 0.2066 indicating that every one percent of increase in farmers' age, ceteris paribus, can increase technical inefficiency by 0.2066 (less than 1%). All this means that the older the farmers are, the more technical inefficiency increases. The findings are the same as Nahraeni et al. stating that the main source of inefficiency is age[21]. However, it is different from the findings of Anggraini et al. where socio-economic factors that have a real effect on reducing technical inefficiency are the farmer's age, harvesting age, and number of family members[22].

Tabel 3. Distribution of Efficiency Levels of Oil Palm Farming in South Labuhan Batu Regency in 2020

Tingkat Efisiensi Petani	Jumlah Petani
< 0,7	1
0,7 – 0,8	5
0,8 – 0,9	16
> 0,9	23
	45
Minimum	0,7376
Median	0,8907
Maximum	0,9809

Source: Primary Data 2020 (adapted)

The distribution of efficiency levels of OPS' farming is based on the approach of Jondrow et al. as shown in Table 3[17]. The average value of OPS' technical efficiency in LBS is 89.07% indicating that they still have the opportunity to obtain higher and more technically efficient production. The opportunity to increase production to achieve the highest production potential is 10.93%. The strategy to maximize such potentials is to increase farmers' knowledge through non-formal education which is directed to how to improve oil palm farming practices.

Boers et. al. explained that improving agricultural practices would increase the efficiency of production volume and income of independent smallholders by 25%[8]. Government support is urgently needed by considering that ISFs are farmers who manage, finance and manage their own plantations, so their productivity is generally lower due to a lack of capital, knowledge and facilities when compared to farmers who have institutions such as plasma and/or cooperatives.

The technical efficiency of 89.07 % is relatively close to the Apriyanti's findings, where the average efficiency of oil palm plantations as a whole is 0.861 in NSP[23]. However, it is different from the results of the study conducted by Napitupulu, et al. where the average level of technical efficiency for oil palm is only 0.6271[24]. According to Azzuhdan et al., the technical efficiency of CPO production shows that the average efficiency value produced is 0.98 which means that technically CPO production is close to full efficient conditions, so only a slight improvement is needed in the use of production factors to achieve optimal CPO production[25].

CONCLUSION

The OPP average is only 15.72 tons of FFB/ha/year, which is still far below the production by private and national plantations run under plasma-nucleus model. The factors influencing the ISFs' production are related to the area planted, the amount of labors, and uses of urea fertilizer and herbicides. The OPP age can reduce both technical inefficiency and level of education; factors that can cause technical inefficiency are concerned with the use of family members, farmers' experience and their age. The total elasticity of response to the use of all inputs estimated using the maximum likelihood method from the translog of the stochastic production function is 1.09, showing how much the ISFs' is under IRS conditions. Judging from the average technical efficiency, the OPS still have the opportunity to reach the potential for productivity and production to the frontier point of 10.93 %. Meanwhile, the ISFs are expected to participate in an economic institution to increase access to information and capital in the production process. It is recommended that future research include institutional and policy elements of the NPDE, RSPO and ISPO which have become national and international guidelines in OPP.

Declaration by Authors

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