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NON-PARAMETRIC APPROACH TOWARDS SMALLHOLDERS RUBBER PRODUCTION EFFICIENCY: A TWO-STAGE DATA ENVELOPMENT ANALYSIS (DEA)

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ABSTRACT

In South Sumatra, Indonesia, the productivity of smallholders' rubber is lower than the productivity of private and government estates. The productivity of Indonesian smallholders' rubber can be enhanced through intensification or technology improvement. The main objective of this study is to estimate the technical efficiency level and technical inefficiency effect model of smallholder's rubber in South Sumatra. A survey was conducted from November 2016 to March 2017 in 11 districts in the South Sumatra Province. 384 rubber farmers were selected using a combination of purposive, multi-stage and random sampling techniques. This study employed a non-parametric approach (Two-stage DEA) using cross-sectional data to understand the rubber production process. The findings showed that the mean technical efficiency of the sampled farms under the VRS DEA was estimated at 0.80. However, the mean technical efficiency was still less than 0.82, indicating that on average, the sampled farms were not technically efficient. Tobit regression results showed that all of the determinants have the expected signs (negative) in relation to technical inefficiency, thus implying that these factors increase technical efficiency as expected. However, only two of the determinants, farming experience and tapping system were statistically significant to the level of technical efficiency.

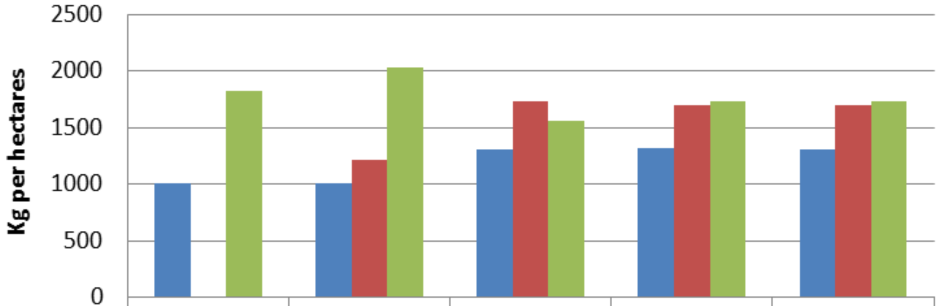
Contribution/ Originality: Low productivity has been a primary issue for Indonesian smallholders' rubber. The best effort to improve rubber productivity is by managing resources more efficiently. This paper contributes to the study production efficiency of smallholders' rubber in Indonesia by employing the two-stage DEA analysis.

1. INTRODUCTION

The rubber plantations in South Sumatra, Indonesia are dominated by smallholders' rubber, which cover an area of 791.187 hectares or about 93 per cent of the total area in South Sumatra. Smallholders' rubber contributed

94 per cent to the total production of 943.965 tons of rubber in 2015. Approximately more than 485 thousand households in South Sumatra rely on rubber production. Thus, rubber provides the livelihood for more than 1.94 million people or about 24 per cent of the total population in South Sumatra, Ministry of Agriculture [1].

In South Sumatra, the productivity of smallholders' rubber was lower than the productivity of private and government estates. In 2015, private estates recorded the highest level of productivity at about 1,736 kilogram per hectare, followed by government estates with a productivity level of 1,697 kilogram per hectare, and smallholders' rubber with a productivity level of 1,302 kilogram per hectare. The growth of rubber productivity in South Sumatra in 2011-2015 is presented in Figure 1.



	2011	2012	2013	2014	2015
Smallholdings	1012	1011	1302	1324	1302
Government		1214	1732	1692	1697
Private	1821	2028	1554	1727	1736

Figure-1. Growth of Rubber Productivity in South Sumatra.
Source: Ministry of Agriculture [1].

The Indonesian government has been concerned about the problem of low productivity among rubber smallholders since the country's independence. Since the 1980s, the government has conducted various rubber development projects as improvement efforts in order to increase smallholders' rubber productivity. The productivity of Indonesian smallholders' rubber can be enhanced through intensification or technology improvement. This effort is more likely fruitful considering the effort to increase rubber production through expansion of rubber areas is not currently possible. Due to the decline in rubber price, in January 2009, Indonesia together with Thailand and Malaysia incorporated under the International Tripartite Rubber Council (ITRC) entered into an agreement to reduce rubber exports according to the Supply Management Scheme (SMS). According to this agreement, these countries have to reduce their respective rubber productions by reducing rubber replanting and new planting in order to gain increased rubber prices in the world market. Therefore, an alternative to be considered in order to increase rubber production is the employment of more efficient resources management. This can be achieved if reliable empirical knowledge on the technical efficiency of resource allocation is available. Thus, it is necessary to quantify the current levels of technical efficiency and determine the factors affecting the technical efficiency of smallholders' rubber production in South Sumatra.

Farrell [2] suggested the estimation of the frontier production function to measure technical efficiency. Based on Farrell's work, frontier models can be categorized as either parametric or non-parametric. According to Charnes, et al. [3] parametric frontiers need a specific functional form which relates the independent variable to the dependent variables. Emrouznejad, et al. [4] stated that in parametric frontiers, determining the exact specification of the error structure is difficult and this may likely to lead to potential sources of error. On the other side, non-parametric frontier methods do not rely on specific functional forms and do not allow statistical noise. Thus, all deviations from production frontier can be explained by inefficiency. Because the non-parametric data envelopment analysis (DEA) approach is easier to be implemented, it has become a popular technique used in efficiency analysis, [5]. The DEA model has been applied to estimate the technical efficiency of annual crops such as turmeric, rice, potato and wheat (Louis and Joel [6]; Umanath and Rajasekar [7]; Mardani and Salarpour [8]; Usman, et al. [9]; Raheli, et al. [10]). Although the DEA has been widely utilized in most studies on annual crop efficiency, it has also been applied in studies on perennial tree crops such as cocoa, oil palm and rubber (Eyitayo, et al. [11], Fadzim, et al. [12], Ali, et al. [13]).

However, the DEA cannot estimate the factors affecting technical efficiency with the frontier production function simultaneously. Therefore, in the DEA, the second stage is required after the estimation of the technical efficiency score in order to estimate the efficiency effect model. In this stage, the score of the DEA technical efficiency estimation as a dependent variable is regressed by the factors affecting technical efficiency as independent variables. The two-stage DEA approach is commonly employed. In the first stage, the non-parametric DEA estimates farms' efficiency scores. As these efficiency scores lie between the 0-1 interval, these estimates are then regressed against the independent variables using the Tobit model in the second stage, Ray [14]. Therefore, the aim of this paper is to use the two-stage DEA to calculate the level of technical efficiency and determine the factors affecting the technical efficiency of smallholders' rubber production in South Sumatra, Indonesia.

2. MATERIALS AND METHODS

2.1. Study Area

The study area is the South Sumatra Province in Indonesia. South Sumatra lies approximately between the latitudes of 1^0 and 4^0 S of the equator and the longitudes 102^0 and 106^0 E of the Greenwich Meridian. The province is bounded to the east by the Bangka Belitung Province, to the west by the Bengkulu Province, to the north by the Jambi Province and to the south by the Lampung Province. The South Sumatra Province has an area of about 8,701,742 square kilometers, which is divided into 17 local government districts/cities and has a total population of 7.701.528 people [15]. The study was conducted in the following 11 districts, which are major rubber areas in the South Sumatra Province: Lahat, Musi Banyuasin, Musi Rawas, Muratara, Ogan Komering Ulu, OKU Timur, Ogan Komering Ilir, Ogan Ilir, Muara Enim, Pali, and Prabumulih Figure 2.

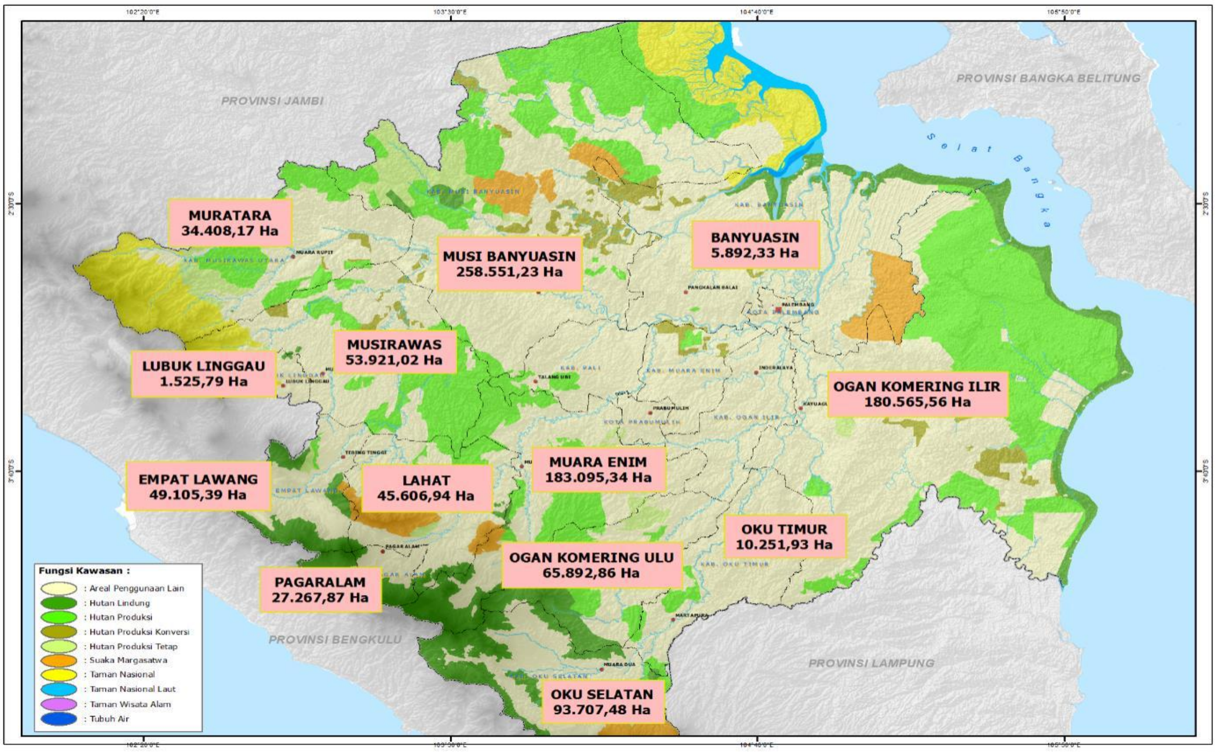


Figure-2. Map of the South Sumatra Province.

Source: Kolega South Sumatra [16].

2.2. Data Collection

The study used primary data that were collected using a structured questionnaire which covered the demographic, farmers' socio-economic, and farm characteristics. The questions asked about the respondents' age of household head, family size, educational level of household head, extension of rubber technology, farming experience, planting material and tapping system. Data requested on production inputs include the total number of trees tapped, age of rubber trees, total amount of fertilizer and herbicide used, and labor used to work the rubber plots. The amount of rubber yield obtained in kilograms (Kg) was also asked in the questionnaire. Other information was obtained from the Indonesian Rubber Research Institute.

2.3. Sampling Technique

The rubber households located in the South Sumatra Province were the target population of this study. 384 respondents were selected to participate in this study using a combination of purposive, multi-stage and random sampling techniques. In the first stage of data collection, South Sumatra was purposively selected as it houses the biggest rubber production area in all of Indonesia. The second stage involved a purposive selection of 11 districts in the selected province due to the predominance of rubber production in these areas. The 11 districts are home to a total number of 411,336 rubber farmers. Then, Krejcie and Morgan [17] was employed to form the sample size of 384 respondents [17]. In the third stage, rubber farmers were selected randomly from each district in a ratio proportional to the size of population of rubber farmers in each district. Analysis was carried out using data on only 380 farmers, as there were inconsistencies and lack of coherence in some of the data collected.

2.4. Data Analysis

The data envelopment analysis (DEA) was employed to estimate the technical efficiency of rubber farms using the *R* programming language and *FEAR* package [18]. Then, the Tobit model was used to estimate the efficiency effect model using the Stata13 software.

2.5. Empirical Methods

2.5.1. DEA Analysis

The DEA calculates technical efficiency scores under the assumptions of constant returns to scale (CRS) and the variable returns to scale (VRS) on a sample of farms. The CRS model assumes that all farms operate at an optimal scale. However, the rubber farmers in the study area were found to deal with many problems such as financial constraints, fluctuating inputs, unreliable labor supply, pests and disease, et cetera that cause only part of the farms to operate at the optimal level. It is suggested that there is no reason to assume that CRS exists in the production of rubber at the farm level. Thus, the use of the VRS was assumed suitable to evaluate the technical efficiency of rubber farms by adding convexity constraints to the constant returns to scale assumption in the DEA model.

The DEA model based on VRS can be specified as the following Banker, et al. [19]:

$$
\begin{aligned}
&\mathrm{Min}_{\theta,\lambda}\ \theta \\
&\text{subject to}\quad -y+Y\lambda \geq 0 \\
&\qquad\qquad\quad \theta x_i - X\lambda \geq 0 \\
&\qquad\qquad\quad \lambda \geq 0 \\
&\qquad\qquad\quad N1'\lambda = 1
\end{aligned}
$$

where

Y = output matrix for 'n' rubber smallholder farms,

X = input matrix for 'n' rubber smallholder farms,

θ_i = VRS technical efficiency score of the ith rubber smallholder farm

λ_j = $n \times 1$ constraint
y_i = output for ith rubber smallholder farm in kilogram,
x_i = inputs vector of x_{1ij}, x_{2ij}, x_{3ij}, and x_{ij4} inputs of the i-*th* rubber smallholder farm,
x_{i1} = Rubber Weighted Trees (RWT) in number
x_{i2} = amount of fertilizer used in kilogram
x_{i3} = herbicide used in liters
x_{i4} = total labor used in man-hours

2.5.2. Tobit Regression Analysis

Following Tijani, et al. [20] the Tobit regression model is stated as:

$$TI_i = \alpha_0 + \alpha_1 x_{i1} + \alpha_2 x_{i2} + \alpha_3 x_{i3} + \alpha_4 x_{i4} + \alpha_5 x_{i5} + \alpha_6 x_{i6} + \alpha_7 x_{i7} + \varepsilon_i$$

Where, TI_i = technical inefficiency score for i-th rubber smallholder; α_0 = intercept coefficient, and $\alpha_1 - \alpha_7$ = parameters to be estimated. The socio-economic determinants include: x_1 = age of a farmer (years), x_2 = family number, x_3 = education, x_4 = extension visit (1 = received extension visit, 0 = never received extension visit), x_5 = experience (years), x_6 = tapping system (1 = S/2 d2, 0 = other than S/2 d2,), and x_7 = type of planting material (1 = rubber clonal, 0 = non rubber clonal).

3. EMPIRICAL RESULTS

3.1. Summary Statistics of Output and Inputs

The sampled rubber farms in this study differ in size, intensity of input use and output. Table 1 provides the descriptive statistics of the inputs and output. Table 1 shows that the average rubber output of the sampled farms is 2,711 kilogram per hectare per year with a minimum output of 1,100 kilogram and a maximum output of 5,480 kilogram per hectare per year.

Table-1. Summary statistics of inputs and output.

Variable	Unit per Ha	Minimum	Maximum	Mean	Std. Deviation
Output	Kg	1,100	5,480	2,711	944
RWT	Number	200	600	397	123
Fertilizer	Kg	67	919	313	134.
Herbicide	Liter	1	14	4	1.987
Labor	Man-hours	459	3,365	1,470	573

Source: Field survey, 2016-2017.

Rubber weighted trees (RWT) is introduced to capture effect of age of trees to rubber productivity. RWT reflected the higher production capacity of mature trees relative to the young and very old trees, Son, et al. [21]. The weights (W's) can be estimated by dividing average rubber weight for each age group to the average weight for those at yield peak (i.e., RT3). During production period, rubber trees have six stage categories, that are W_1= rubber trees aged 6-10 years, W_2= rubber trees aged 11-14 years, W_3= rubber trees aged 15-18 years, W_4= rubber trees aged 19-22 years, W_5= rubber trees aged 23-26 years, and W_6= rubber trees aged 27-30 years. In this study, the average rubber weight based on yield profile for RT_1; RT_2; RT_3; RT_4; RT_5 and RT_6 are 800; 1,775; 1,800; 1,675; 1,600 and 1,350 kilogram per hectare, respectively. Thus, the W's estimates are: W_1 for RT_1= 800/1800 = 0.44; W_2 for RT_2 = 1775/1800 = 0.98 ;W_3 for RT_3 = 1800/1800 = 1; W_4 for RT_4 = 1675/1800 = 0.93; W_5 for RT_5 = 1600/1800 = 0.89; W_6 for RT_6 = 1350/1800 = 0.75. Then, the weight (W's) obtained is multiplied by the number of trees at related age categories (RT's). From the results, the average RWT of sampled farms per hectare was 397 and ranged between 200 and 600. The average total fertilizer used per farm was 313 kilogram per year and ranged between 67 kilogram and 919 kilogram per hectare per year. The average herbicide used per farm was 4 liter per hectare per year, and ranged between 1 liter and 14 liter per hectare per year. The average total labor used per farm was 1,470 man-hours per hectare per year and ranged from 459 to 3,365 man-hours per hectare per year.

3.2. Socio-Economic Characteristics of Respondents

Table 2 provides descriptive statistics of socio-economic characteristics of respondents in study area. From the data of total respondents, there were about 36% of respondents falling within the age group of 36-44 years. On average, the respondents were 44 years old. A farms household consists of husband, wife and children, as well as other dependents living with them. The data showed that about 37% of the sampled rubber farmers had household size of three. On average, the sampled farmers have 4 household members. Table 2 showed that about 2% of the farmers never received formal education. It is observed that 37 per cent of the farmers completed primary school education; 23 per cent of them finished junior high school, 32 per cent of them completed senior high school; only 6 per cent of them were diploma/university degree holder.

Table-2. Socio-economic characteristics of respondents.

Variables	Frequency (n)	Percentage (%)
Farmers' age (years)		
18 - 26	7	2
27 - 35	83	22
36 - 44	137	36
45 - 53	76	20
54 - 62	58	15
63 - 71	19	5
Total	**380**	**100**
Family Size (number)		
2	74	20
3	139	37
4	97	26
5	45	12
6	19	5
7	5	1
8	1	0
Total	**380**	**100**
Education		
No education	9	2
Primary school	140	37
Junior high school	88	23
Senior high school	122	32
Diploma/university	21	6
Total	**380**	**100**
Extension		
Never Received extension	244	64
Received extension	136	36
Total	**380**	**100**
Experience		
2 - 9	46	12
10 - 17	127	33
18 - 25	111	29
26 - 33	58	15
34 - 41	32	8
42 - 49	6	2
Total	380	100

Table-2. Socio-economic characteristics of respondents (Continued).

Variables	Frequency (n)	Percentage (%)
Tapping System		
S/2 d2	60	16
Other than S/2 d2	320	84
Total	380	100
Planting Material		
Non Clonal	194	51
Clonal	186	49
Total	380	100

Source: Field Survey, 2016-2017.

The majority (64%) of the respondents never received extension visits. Only about 36% of respondents had access to extension services. About 33% of the respondents had rubber farming experience of 10-17 years. The mean rubber farming experience was 19 years for the sampled rubber farmers. In term of tapping system, only about 16 per cent of respondents used recommended tapping system of S/2 d2. It is observed that about 49 per cent of respondents utilized rubber clonal.

3.3. Technical Efficiency

The technical efficiencies of 380 sampled rubber smallholders in Indonesia were examined under DEA-VRS Table 3. From Table 3, under the VRS assumption, the technical efficiency estimates shows that rubber smallholders operate between 0.4001 and 1.0000 efficiency scores. The mean technical efficiency estimation of the VRS was calculated and found to be 0.80. As the mean technical efficiency was less than 0.82, it indicates that on average, the sampled rubber farms are not technically efficient [22].

The results further show that about 8.7 per cent of the smallholders were fully technically efficient. This suggests that about 91.3 per cent of rubber smallholders were technically inefficient. Compared to other countries, this mean that the technical efficiency of smallholders in Indonesia under VRS is still comparable with the technical efficiency of rubber smallholders in Thailand (TE_{VRS} = 0.85) [23]. However, it is still lower than the technical efficiency of rubber smallholders in Malaysia (TE_{VRS} = 0.95) [24].

Table-3. Frequency distribution of technical efficiency scores obtained using the DEA Model.

Efficiency Score	Frequency (n)	Percentage (%)
<0.2000	0	0.0
0.2001-0.3000	0	0.0
0.3001-0.4000	0	0.0
0.4001-0.5000	4	1.1
0.5001-0.6000	28	7.4
0.6001-0.7000	62	16.3
0.7001-0.8000	72	18.9
0.8001-0.9000	115	30.3
0.9000-0.9999	66	17.4
1.0000	33	8.7
Total summary	380	
Mean	0.80	
Std. Deviation	0.13	
Min	0.46	
Max	1.00	

Source: Field survey, 2016-2017.

Generally, the mean efficiency value shows that smallholders produce rubber at 80 per cent efficiency level due to the inefficiency of rubber smallholders in the study area. The mean efficiency value shows that rubber farmers can reduce their input by 20 per cent to continue to produce the same bundle of output, or the smallholders can produce around 20 per cent more of output by using the same inputs in order to be fully efficient.

3.4. Factors Affecting Technical Inefficiency

In the second stage of the two stage-DEA analysis, the technical inefficiency scores obtained from the DEA analysis at the first stage under VRS were regressed against rubber smallholders' characteristics along with institutional and farm practices that influence technical inefficiency using the Tobit model. In this analysis, the scores of technical efficiency of VRS are used as the dependent variable, and rubber smallholders' characteristics, institutional and farm practices act as independent variables. The independent variables consist of farmers' age, family size, education level of household head, extension visit, farming experience, tapping system, and planting material. The estimation results of the Tobit regression are presented in Table 4.

Table-4. Tobit regression model of factors affecting technical inefficiency.

Variable	Parameters	Coefficient	Std. Error	t-ratio
Constants	□0	0.3557	0.0393	9.06***
Farmer's age	□1	-0.0012	0.0009	-1.31
Family Size	□2	-0.0009	0.0059	-0.15
Education	□3	-0.0099	0.0072	-1.39
Extension	□4	-0.0147	0.0163	-0.90
Experience	□5	-0.0035	0.0011	-3.18***
Tapping System	□6	-0.0381	0.0197	-1.93*
Planting Material	□7	-0.0212	0.0144	-1.47

Source: Field survey, 2016-2017

Table 4 suggests that all of the determinants have the expected signs (negative) in relation to technical inefficiency, implying that these factors increase technical efficiency as expected. However, only two determinants were statistically significant to the level of technical efficiency. These two determinants are experience and tapping system. The negative coefficient of experience is significant in relation to technical inefficiency, suggesting that technical inefficiency in rubber production would likely decrease as the smallholders' experience in rubber farming increases. This is in line with the study results of Danso-Abbeam, et al. [25]. The coefficient of tapping system shows a significant and negative sign in relation to technical inefficiency, suggesting that the recommended S/2 d2 tapping system could increase rubber production efficiency. This is similar with the study results of Aliyu, et al. [26].

4. CONCLUSION

The results of the data envelopment analysis (DEA) which showed that the mean technical efficiency estimate is 0.80 prove that the sampled rubber farms are not technically efficient. The smallholders can produce around 20 per cent more of output by using the same inputs in order to be fully efficient. Therefore, this study suggests that the Indonesian government should enhance research and provide more information to farmers in order to improve the management and allocation of production inputs that could in turn help improve the smallholders' rubber efficiency. The results of this study prove that farming experience and the recommended tapping system have significant contribution to rubber technical efficiency. It implies that rubber production efficiency could be improved by adopting these farming technologies. For the extension program, experienced farmers can be the target participants in order for the extension effect to be efficiently perceived by the farmers. Such knowledge could help improve these smallholders' efficiency. In terms of tapping system, the government should also provide regular training on rubber tapping systems to rubber smallholders, extension staffs and other technical staffs.

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