

Estimating Technical Efficiency and its Determinants in the Coconut Plantations: The Case of Kurunegala Plantations Limited, Sri Lanka

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Abstract

This study estimated the Technical Efficiency (TE) of coconut production in Sri Lanka using the stochastic frontier production function procedure. Data on inputs and coconut production recorded by Kurunegala Plantations Limited from 2000 – 2018 were used for the analysis. The stochastic production frontier in Cobb-Douglas form and the inefficiency model were estimated by single-step Maximum Likelihood method using STATA 14 computer software package treating coconut yield as the dependent variable and fertilizer, rainfall, labor, chemicals, tractor hours, mulching harrowing/plowing, agro-ecological zones, education level of the managers and bearing coconut extent as independent variables. Results revealed that TE of coconut production ranged from 81-98%, with an average of 88%, indicating that there is scope for increasing the production by as much as 12% without increasing inputs and simply using a higher technology level. The outcome of the analysis shows that inorganic fertilizer, rainfall, labor, tractor hours, and mulching are kind positive and significant. In contrast, agro-chemicals such as weedicides, fungicides and pesticides and plowing/harrowing did not show a significant contribution to coconut production. In respect of the farm and farmer-specific characteristics, the size of the estate has a positive relationship with technical inefficiency, meaning that smaller estates are more efficient than larger estates. It also shows that the agro-ecological zones and educational level have no significant effect on the efficiency of coconut production. The results highlight the need for government and private sector assistance in improving the efficiency of smallholders and promoting access to productive inputs.

Keywords: coconut plantations, stochastic frontier, technical efficiency, fertilizer response in coconut

Introduction

Coconut, one of the major plantation crops in Sri Lanka, plays a vital role in sustaining the national economy, food security, and people's livelihood. Coconut cultivation occupies 20% of the total agricultural land in the country (DCS, 2014) while contributing to GDP and export earnings around 0.7% and 5.1%, respectively (CBSL, 2019). This sector employs around 135,000 people in production and industry and provides a livelihood for 698,168 smallholders (DCS, 2012). The annual average coconut production is about 2,800–3,000 million nuts, of which approximately 70% is utilized for domestic culinary purposes and the balance is divided among value-added coconut-based processing industries (CDA, 2019). Over the years, the country's coconut production remains stagnant while the demand for coconut for culinary nuts and industrial use is increasing. Coconut supply has been

uncertain due to many reasons such as the impact of climate change, price fluctuation, high cost of production, pests and diseases, fragmentation of coconut lands, scarcity of labor, etc. Limitation of increasing of coconut supply is attributed by availability and opportunity cost of suitable land for the cultivation, a constraint of capital, declining production of old senile coconut palms. Since, there is a limited scope to increase the coconut supply either by expanding the area under the coconut or increasing the use of costly inputs such as labor and fertilizer, exploring the ways and means to obtain the maximum gains from the more efficient use of existing technology with given inputs is justified.

Coconut is grown under various agro-ecological zones and other characteristics such as availability of inputs and different management practices. Therefore, the performance of these production units is diverse. There are various measures to assess the performance of a production unit, and among them,

productive efficiency is an important measurement of producer performance. Technical efficiency (TE) measurement is one of the most commonly used methods for measuring the production performance of an economic unit. The TE determines the level of efficiency of an economic unit which will enable the identification of the factors by which improvements can be made while providing useful information for policy formulation. Since there is little empirical evidence of the technical efficiency of coconut production, it necessitates an analysis of the production efficiency of the major coconut producers to determine the magnitude of gains arising from minimizing inefficiencies while helping in formulating policy measures to reduce the production constraints. Hence, the objectives of this study were to estimate the technical efficiency by using stochastic frontier analysis (SFA) of coconut production, identify the key determinants of inefficiency, and rank the estates according to the TE.

Methodology

Technical efficiency in crop production can be defined as a farmer's ability to maximize outputs under a given set of inputs and technology (Mango, et al., 2015). The degree of technical inefficiency reflects an individual farmer's failure to attain the highest possible output level given the set of inputs and technology used. The highest possible output, using available input and technology, is represented by the production frontier. The distinction between technological change and technical efficiency is important. The technological change reflects a shift of the production frontier, as new technologies enable output per unit of input to increase (Bravo-Ureta, 2007). Technical efficiency, on the other hand, explains the difference between potential and observed yield for a given level of technology and inputs.

Theoretical framework

Theoretically, the productive efficiency of a firm consists of two components: technical efficiency, which reflects the ability of a firm to obtain maximal output from a given set of inputs, and allocative efficiency, which reflects the ability of a firm to use the inputs in optimal proportions, given their respective prices. These two measures are then combined to measure total economic efficiency or productive efficiency (Farrell, 1957). These measures can be input or output orientation. Later, this has been evolved to develop a stochastic frontier approach for parametric function such as Cobb-Douglas form or non-parametric piecewise-linear technology and evolved to Data Envelopment Analysis (DEA) approach. The estimation of frontier function and efficiency can be completed either in one stage or in two stages. The two-stage analysis of explaining the level of technical efficiency (or inefficiency) was criticized by Battese and Coelli (1995) as being contradictory in the assumption made in the separate stages of analysis. This study follows the Battese and Coelli (1992) approach of modeling both the stochastic and technical inefficiency effect in the

frontier using maximum likelihood in a single-step analysis in Cobb-Douglas form to assess the stochastic production frontier of coconut production at the estates level.

The stochastic frontier models introduce a disturbance term representing statistical noise, measurement error, and exogenous shocks beyond the control of the production unit, which would otherwise be attributed to technical inefficiency and provides the basis for conducting statistical tests of hypothesis regarding the production structure and the degree of inefficiency. This model is composed of an error structure comprising a two-sided symmetric term and a one-sided component. The two-sided error captures random effects outside the control of the plantations, including the weather conditions, measurement errors, or other random disturbances typical of empirical data, while the one-sided non-negative component reflects the technical inefficiency. The stochastic production frontier model was specified as:

$$y_i = (x_i; \beta) \exp f(v_i - u_i), i = 1, 2, \dots, N \quad (1)$$

Where y_i denotes the output of single farm i , $f(\cdot)$ is the production frontier, x_i represents a vector of the inputs used on the i^{th} farm, β is a vector of unknown coefficients to be estimated, v_i is the two-sided error and u_i is the one-sided error representing technical inefficiency (TIE). The two-sided error v_i is assumed to be independently and identically distributed as $N(0, \sigma_v^2)$, while u_i is assumed to have a half-normal distribution, i.e. a non-negative truncation of the $N(0, \sigma_u^2)$ distribution. The outputs can either be measured as quantities for a single crop or more than one crop. The measure of technical efficiency (TE) relative to the production frontier are defined as:

$TE = Y_i / Y_i^*$, where $y_i^* = f(x_i, \beta)$ highest predicted value for the i^{th} firm

The TE of the production for the i^{th} farm was defined as the ratio of observed production to the maximum feasible production as the following equation:

$$TE_i = \frac{f(x_i; \beta) \exp(v_i - u_i)}{f(x_i; \beta) \exp(v_i)} = \exp(-u_i) \quad (2)$$

Battese and Coelli (1988) suggest that TE should be predicted using its conditional expectation, given the composed random error, $v_i - u_i$, evaluated at the maximum-likelihood estimates of the equation (2). In the case of a production frontier, TE_i will be valued between zero and one, therefore,

Technical inefficiency = $1 - TE_i$

According to Battese and Corra (1977), the variance ratio parameter γ , which is related

to the $\gamma = \sigma_u^2 / \sigma^2$
where, $\sigma^2 = \sigma_u^2 + \sigma_v^2$
So that $0 \leq \gamma \leq 1$

When γ is close to 0, the difference between yield and efficient yield is entirely due to statistical noise. On the other hand, if the γ is close to 1, the difference is attributed to the growers' less efficient use of the technology.

To estimate the factors that contribute to TIE, we applied the model which was proposed by Battese and Coelli (1995), specified as:

$$TIE_i = Z_i \delta + \omega_i \quad (3)$$

Where z is a $(1 \times M)$ vector of explanatory variables affecting TIE, δ is an $(M \times 1)$ vector of coefficients to be estimated, and ω_i are unobservable random errors defined by the truncation of the normal distribution.

$$N(0, \sigma^2), \text{ such as that } w_{i \geq -z_i} \delta \quad (4)$$

In this study, we use the panel data. Pitt and Lee (1981) specified a panel data version of the Aigner, Lovell and Schmidt (1977) half-normal model as follows:

$$\ln y_{it} = f(x_{it}; \beta) + v_{it} + u_{it} \quad \parallel \quad i = 1, 2, \dots, N, t = 1, 2, \dots, T \quad (5)$$

Where $f(\cdot)$ denotes a suitable functional form, in this study we use Cobb-Douglas functional form using maximum likelihood estimation (ML).

Empirical model

The stochastic production frontier in Cobb-Douglas form and the inefficiency model were estimated by single-step Maximum Likelihood method using STATA 14 computer software package treating coconut yield as the dependent variable and fertilizer, rainfall, labor, chemicals, tractor hours, mulching harrowing/plowing as independent variables in the stochastic frontier model while agro-ecological zones, education level of the managers and bearing coconut extent as independent variables in the inefficiency model. The empirical models for both the stochastic frontier model and the inefficiency model are stated in equations 6 and 7. A range of factors, including estate level characteristics and socio-economic, environmental, and non-physical, are likely to affect the efficiency of coconut growers. According to past studies, the responsiveness of coconut production to some inputs such as fertilizer and rainfall has proven the presence of lag effects. Therefore, two years lag for fertilizer (De Silva, 1972) and one-year lag for the rainfall were used in the model where it is necessary to represent the characteristic nature of the coconut cultivation.

$$\ln Y_i = \beta_0 + \beta_1 \ln LBO + \beta_2 \ln FER_{i,2} + \beta_3 \ln CHE + \beta_4 \ln RF_{i,1} + \beta_5 \ln MAC + \beta_6 \ln MUL + \beta_7 \ln PUL + v_i + u_i \quad (6)$$

Where,

Y_i = Annual coconut production (Nuts/year)

LBO = Labor (Man days)

FER = Fertilizer (Kg)

CHE = Agro chemicals (Liters)

RF = Annual rainfall (mm)

MAC = Machinery usage (Tractor hours)

MUL = Mulching base on the coconut trees (Number of the coconut trees)

PUL = Ploughing /harrowing (Hectares)

$\beta_0 - \beta_7$ = Coefficients to be estimated

v_i = Independently and identically distributed random errors

u_i = Non-negative random variables which are independently and identically distributed

In the inefficiency model; equation 7, non-negative error U_{it} is expressed as a function of the agro-ecological zone, educational qualifications of the management, and the bearing coconut extent. W_{it} is an unobservable random error.

$$U_{it} = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 Z_3 + W_{it} \quad (7)$$

Where,

U_{it} = Non-negative random variables

Z_1 = Agro-ecological zones (1 for wet zone and 0 for intermediate zone)

Z_2 = Educational levels of the management (1 for basic 0 for diploma-level and above)

Z_3 = Bearing coconut extent (ha)

$\delta_0 - \delta_3$ = Coefficients to be estimated

W_{it} = Unobservable random variables

The coefficients of the variables for both stochastic production frontier and technical inefficiency models were estimated by one step Maximum Likelihood (ML), time-invariant, fixed effect, output-oriented model using the computer program STATA.

Data collection and analysis

Secondary panel data available in nine area estates belonging to Kurunegala Plantations Ltd. over nineteen years from 2000-2018 were used for the analysis. The estates are Attanagalla, Dambadeniya, Dodangaslanda, Hiriyala/Wariyapola, Dhathusenapura, Katugampola, Mahayaya, Narammala and Kurunegala. These estates are situated in Kurunegala and Gampaha districts that cover the major coconut growing area of Sri Lanka. The company has maintained records of input used, output, and other management practices.

Results and Discussion

Descriptive statistics of the sample

The summary statistics of the variables used in the stochastic frontier model and inefficiency model are presented in Table 1. In terms of socio-economic characteristics, since the Kurunegala Plantations Limited (KPL) is a fully

government-owned plantation management company, a lot of guidelines have been issued for the management of the estates; thereby, farmer-specific characteristics are controlled. However, the bearing coconut extent and two dummy variables, namely agro-ecological zones, and the manager's education levels were considered to analyze the inefficiency model. In the agro-ecological zones, the majority of the sample, 68%, belongs to the Intermediate Zone while 32% belongs to the Wet Zone. Among the managers of the estates, while 62% have basic educational qualifications 38% have obtained higher educational qualifications (Diploma and above).

Results of the stochastic frontier model

Table 2 shows the maximum likelihood estimates of the stochastic frontier production function model and inefficiency model with the determinants of the technical efficiency defined by equations 6 and 7. As shown in Table 2, the estimate of γ is 0.59, which indicates that only 59% of the total variation in coconut output was due to technical inefficiency. Therefore, the difference between coconut yield and efficient yield in the KPL is mainly due to technical inefficiency. This value is lower than the values recorded by Mangika et al. (2009) and Selvam et al. (2018). They have recorded an estimate of 0.85 and 0.84 for γ in a study conducted for assessing the technical efficiency of smallholder coconut growers in Sri Lanka and the Coimbatore District in India, respectively. However, in both studies, the focus was on smallholder coconut growers.

The ML estimates of inorganic fertilizer, rainfall, labor, tractor hours, and mulching are positive and significant at 1% significant level. The estimated ML coefficients of agrochemicals and plowing/harrowing did not show a significant contribution to coconut production. The positive significant coefficient of inorganic fertilizer application of 0.16 indicates that a one-unit increment of fertilizer application will increase coconut output by 0.16. This finding is in line with Selvam et al. (2018) and Omar and Fatah (2021). However, it

is noteworthy that most of the studies (Mangika et al. 2009; Nor et al. 2020), which assessed the technical efficiency among coconut smallholder farmers, have reported that the application of fertilizer has no significant effect on coconut production. Rainfall has a positive significant coefficient of 0.43, indicating that a one-unit increment in rainfall will realize a 0.43 increment in coconut output. Labor input is also positive and significant in the estimated model. The plantation sector has employed skilled laborers, and they are continuously supported with necessary training. Hence, the positive effect of labor on coconut output is justified. Tractor hours have a positive significant coefficient of 0.30, indicating that one-unit increment in tractor hour will realize a 0.30 increment in coconut output. Mulching of the coconut trees with fronds had an elasticity of 0.26 indicates that a 1% increase in mulching (one coconut tree) would lead to a 0.26% increase in coconut output. A minimum of 12 fronds fall annually from a coconut tree, and growers use these to thatch the bases of the coconut trees. Mulching can conserve moisture and provide an organic source of fertilizer and thereby enhance the output of coconut. The analysis of the returns to scale can be done based on the estimates of the stochastic frontier production function in Table 2. Determining the scale benefit of coconut production can be done by summarizing the input coefficients other than the agrochemicals and harrowing/plowing factors. The sum of the coefficients is 1.34, which implies that the coconut production system in KPL operates at increasing returns to scale.

The effect of farm and farmer-specific factors on inefficiency was estimated together with the production frontier. The estimated coefficients of the inefficiency model are shown in Table 2. Accordingly, only the size of the estate denoted by bearing coconut extent is the key factor affecting the technical efficiency of coconut plantations. The other variables; viz. agro-ecological zone and the manager's education level, are not statistically significant.

Table 3. Illustrates the mean, minimum and maximum technical efficiency of all the estates belonging to KPL. According to Table 3 mean, minimum, and maximum technical efficiency of the estates belonging to KPL are 88%, 58%, and 99%,

Table 1. Summary statistics for variables in the production function and Inefficiency model

Variable	Obs.	Mean	Std. Dev.	Min	Max
Variables used in Production model					
Yield (nuts)	171	1,620,210.00	752,190.50	408,55.00	3,178,705.00
Rainfall (mm)	171	1,955.89	548.08	1,022.00	3,886.80
Labor (man-days)	171	21,049.87	10,025.29	386.00	45,928.00
Fertilizer (kg)	171	46,896.01	27,854.02	1,200.00	138,783.00
Chemical (L)	171	64.97	69.86	1.00	308.00
Tractor meter hours	171	2,051.28	1,075.27	33.00	4,984.50
Mulching (No of trees.)	171	28,467.08	22,494.6	250.00	148,032.00
Ploughing (ha)	171	27.77	33.30	0.32	235.00
Variables used in Production model					
Bearing extent (ha)	171	380.10	142.81	37.11	669.01

Source: Author's estimates

Table 2. Maximum likelihood estimates for parameters of the stochastic likelihood production frontier and inefficiency models

Variable	Parameter	Coefficient	Std. Error	Z value	P-value
Stochastic frontier					
Ln (Fertilizer)	β_1	0.16***	0.036	4.70	0.00
Ln (Rainfall)	β_2	0.43***	0.10	4.14	0.00
Ln (Labor)	β_3	0.19***	0.062	3.07	0.00
Ln (Chemicals)	β_4	-0.01	0.021	-0.65	0.51
Ln (Tractor hours)	B_5	0.30***	0.082	3.77	0.00
Ln (Mulching)	B_6	0.26***	0.48	5.39	0.00
Ln (Harrowing /Ploughing)	B_7	-0.01	0.26	-0.53	0.594
Year	β_0	-0.02**	0.01	-2.29	0.02
Inefficiency model					
Agro ecological zone	δ_1	-9.96	24.54	-0.41	0.68
Education level	δ_2	-0.19	0.32	-0.61	0.54
Ln (Bearing coconut extent)	δ_3	0.08***	0.62	2.97	0.00
Constant		-1.16	-	-	-
u-sigma – cons		-2.59			
v-sigma –cons		-1.16			
Sigma u		0.272			
Sigma v		0.227			
Inefficiency model					
Likelihood ratio		-8.38			
Probability>Chi ²		0.00			
Number of obs.		171			
Gamma (γ)		0.59			

Source: Author's estimates

Notes: *** p<0.01 significant at 1%, **p<0.05 significant at 5%, *p<0.10 significant at 10%

respectively, which indicates that there is a 12% scope of increasing the production of coconut in KPL without incurring any additional cost.

The outcome of the analysis was compared with other major agricultural products. There was no considerable difference in technical efficiency except the tea smallholding sector (Basnayake and Gunaratne, 2002) and the paddy farming system in the DZ (Udayanganie et al., 2006); other sectors showed efficiency above 70 percent. In addition, several studies estimated technical efficiency, including; Amarasinghe and Weerahewa (2001) on potato production (72%); Gunathilake and Gajanayake (2008) on dairy farms managed by NLDB (71%), Mangika et al. (2009) on coconut sector (74%), Amarasuriya et al. (2010) on pineapple (85%).

Ranking of the estates according to the technical efficiency
Ranking the estates according to the mean technical efficiency is important to identify the best performer and to develop strategies to improve the productivity levels of the estates. The distribution of mean technical efficiency of the estates calculated by weighted average from the pooled data output is illustrated in Fig.1. Accordingly, the Attanagalla estate

Table 3. Mean, minimum and maximum technical efficiency

Variable	Obs.	Mean	Std Dev.	Min.	Max.
Technical efficiency	171	0.88	0.0817	0.58	0.99

Source: Author's estimates

shows the highest technical efficiency of 98%. In contrast, Katugampola estate shows the lowest technical efficiency of 81%. The mean technical efficiency of other estates varies in between, indicating that there is a potential to increase the estates' technical efficiency.

Conclusion and Policy Implication

This study used the stochastic production frontier method to estimate technical efficiency and identify the determinants of technical efficiency of coconut plantations. The results revealed that the mean technical efficiency of coconut plantations

belonging to KPL estimated using Cobb-Douglas production frontier is 88% indicating that 12% of the maximum potential productivity is lost due to technical inefficiency of the estate-specific characters. Moreover, this indicates that there is a scope for further increasing the output by 12% with a given level of technology and without increasing the level of inputs. The outcome of the analysis suggests that increment application of fertilizer, labor, tractor hours, mulching, and experience of rainfall will significantly increase coconut production. The agrochemicals and plowing/harrowing did not show a significant contribution to coconut production. From the farm and farmer-specific characters, the size of the estate has a positive relationship with technical inefficiency, suggesting that larger estates are less efficient than smaller estates.

The policy implications of these findings are that the technical efficiency of coconut estates could be increased by 12% on average through better use of available resources such as fertilizer, labor, tractor hours, mulching, and supplementary irrigation, given the current state of technology. This could be achieved through awareness programs. The small-scale coconut plantations have more technical efficiency indicating that government and private sector assistance is necessary to improve the productivity of the small-scale coconut plantations. Continuous improvement of the technical efficiency of coconut production could promote income growth and profitability of the plantations. However, this study could only assess technical efficiency in large-scale coconut plantations, which could be extended to smallholders to suit them. The analysis contributes to government policy to expand the small-scale coconut plantation on abounded paddy fields and current debate on the banning of inorganic fertilizer.

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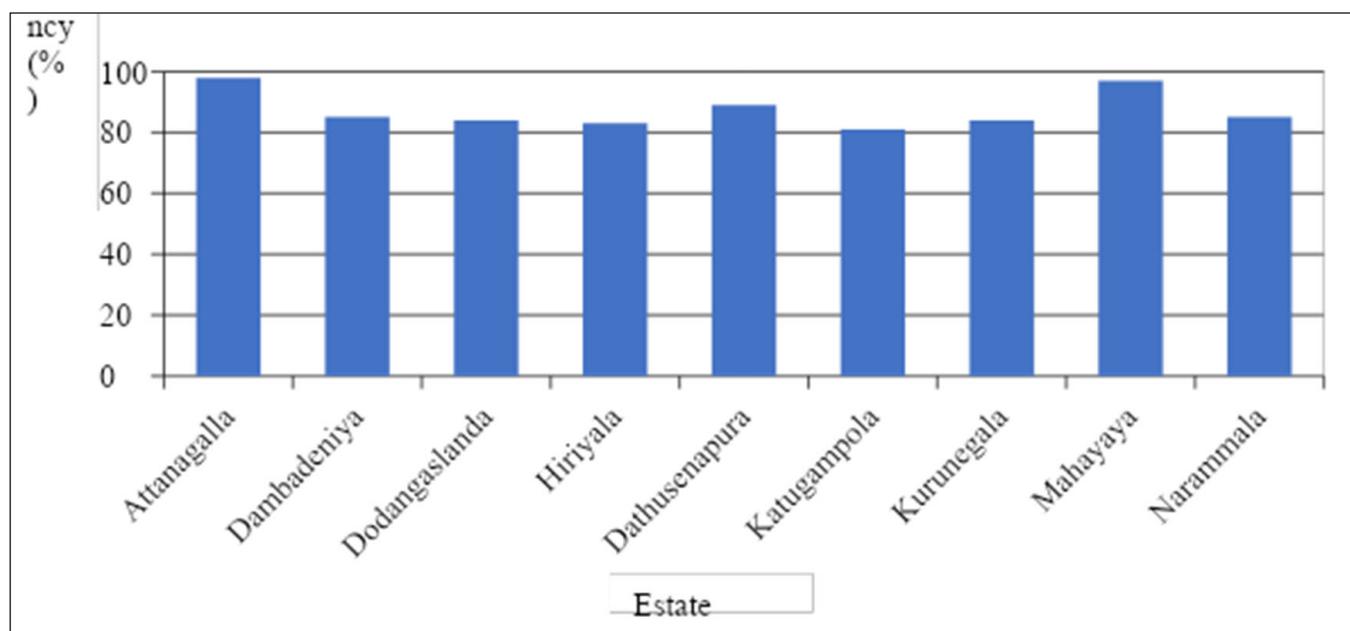


Figure 1. Mean technical efficiencies of area estates (2000-2018)

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