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A Stochastic Production Frontier Approach: Determinants of Technical Efficiency in Small Scale Tea Farmers

Joshua Mwanguhya[1,*], William Ekere[2]

[1]School of Education, Mountains of the Moon University, Fort Portal, Uganda
[2]Department of Agribusiness and Natural Resource Economics, Makerere University, Kampala, Uganda
*Corresponding author: joshua.mwanguhya@gmail.com

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Abstract Most small-scale tea farmers have still failed to produce a recommendable among of green tea yield per hectare with Ugandan tea out-growers producing half of what their counterparts produce per hectare in Kenya and Malawi. Using a random sampling technique 220 respondents were interviewed using structured questionnaires, 110 were small scale contract tea out growers while 110 were small scale non-contract tea out growers. A stochastic production frontier was used to estimate the technical efficiency scores of both categories of farmers and the technical efficiency scores were regressed against socio economic characteristics of the tea farmer using the Tobit model to determine which factors influence technical efficiency of small-scale tea farmers. The results indicated a significant mean score difference between technical efficiency of contract and non-contract tea out-growers. The results further established that, quantity of fertilizer used by contract and non-contract out-growers and access to credit were positive determinants of technical efficiency while age squared of the farmer, size of land under tea cultivation and off-farm income related activities were found to negatively affect technical efficiency scores. Policy makers should make further efforts in strengthening financial institutions like micro finance and other arrangements that can relax farmers' liquidity constraints and help them afford traditional inputs.

Keywords: *technical efficiency, tea out-growers, stochastic production frontier*

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1. Introduction

Uganda is the third largest tea producer and exporter (45,000MT) in Africa after Malawi (55,00MT) and Kenya (295,000MT) MAAIF, [1]. In most countries engaged in tea production, out-growers are contracted by factories to supply green tea leaves. It is estimated that approximately 60,000 out-growers are engaged in tea growing in Uganda. As a result, the tea subsector in Uganda supports the livelihood of around 1.52% of the population of 33 million people Bank of Uganda, [2]. This has been achieved by a privatization policy and the return of estates to former owners who were chased away by former President Idi Amin Dada in the 1970’s resulting into the growth of out-growers engaged in contract farming with factory owners. For a crop like tea, a farmer requires to have sufficient capital to purchase fertilizers and also process the green leaf immediately after harvest which is a challenge for small scale farmers who are financially constrained. However, contracting out-growers and selling to established factories make a viable option for smallholder cash crop farming according to Baumann, [3]; Kirsten and Sartorius, [4].

Tea production in Uganda is done by both large estates (46% of production) and small growers organized as either small estates affiliated with particular tea factory or small scale out-growers producing 54% of the tea. Out-growers produce approximately 28% of the total production of tea with the remaining 72% produced by the tea estates. Presently, the number of out-growers has increased from 14,000 to 60,000 with tea growing expansion to several districts MAAIF, [1] and Bank of Uganda, [2]. The current trend in the growth of smallholders and increased production is because, tea appears to be very attractive to smallholders providing work and income throughout the year, requires little investment, and the risk of disastrous crop failure is fairly low Oxfam, [5].

2. Problem Statement

One of the major objectives of stakeholders in the tea industry is to increase production on a sustainable basis at the farm level. Proper farm maintenance through increased use of inputs like pesticides and fertilizers is considered to be the most effective way to increase production. Binam et al., [6] and Dzene, [7]. For tea to continue to play its key role in Uganda's economy, producers ought to optimize resource use in the industry. However, most small-scale tea farmers have still failed to produce a recommendable among of green tea yield per hectare with Ugandan tea out-growers producing an average yield of 1,348kg per hectare compared to other large tea farming countries in Africa like Kenya and Malawi who produce an average of 2,470kg.

It's from this background that motivated an empirical study to investigate technical efficiency among different small-scale tea farmers is a necessary first step to improving resource use efficiency in specific production areas, boost production, and improve the overall contribution of the tea sub-sector to local economic development and overall national development. This study sought to characterize socio-economic attributes of both contract tea out grower and non- contract tea out grower farmers; determine and compare the technical efficiency for both contract out grower and non-contract out grower tea farmers and finally establish factors affecting technical efficiency of contract and non-contract tea out-growers.

3. Methodology

The study was conducted in Kyenjojo district located in Western Uganda. Kyenjojo district was purposefully selected because it's the second largest tea producer in the country. The sampling method that was used is a Multi-stage sampling technique. In the first stage purposive sampling was employed and this resulted into the selection of the study area that is Kyenjojo district and the two counties of Mwenge South and North based on the population of tea farmers and availability of market for the tea, in these two counties seven sub-counties were selected from the nine sub-counties because they are major tea producing sub-counties; in Mwenge North Bufungo, Nyakwanzi and Kyarusozi were selected while in Mwenge South Bugaki, Butiiti, Kihuura and Kyenjojo town council where selected. In the second stage simple random sampling was used to select the contract out growers and non-contract out growers. A list of tea farmers was obtained from the factories with the help of extension workers and sample of 110 contract tea out grower farmers and 110 non-contract tea out grower farmers were randomly selected making a total sample of 220 small scale tea farmers which was considered sufficient for a rigorous econometric analysis. From two villages in each of the seven-sub county, 15 contract tea out growers and 15 non-contract out-growers were selected with an exception of Kyarusozi sub county which has a quit a large number of tea farmers so 20 contract tea out growers and 20 non-contract tea out-growers were selected.

Descriptive statistics were used to characterize socio-economic attributes of both contract and non-contract out-grower tea farmers. Frequencies, percentages, standard deviation, and means of variables were compute and t-test was used to determine if the means of continuous attributes were statistically different between contract out growers and non-contract out grower small scale tea farmers.

The second objective was achieved by estimating technical efficiency of contract out grower and non-contract out grower tea farmers. These results were used to establish whether contract farmers were more or less technically efficient compared with non-contract farmers. Following Raham [8], technical efficiency of tea production was estimated using a stochastic production frontier, which is specified as

$$Y = f\left(X_i, \beta\right) exp\ \delta \quad (1)$$

As earlier defined, Y, X_i and β_i are vectors of output, input levels and parameter estimate respectively. The error term is "composite" Chavas et al., [9]. Implying,

$$\delta = \nu - \mu \quad (2)$$

Where v is a two-sided $(-\infty < \upsilon < \infty)$, normally distributed random error $[V \approx N(0, \sigma_\vartheta^2)]$ that captures the stochastic effects outside the farmer's control (e.g weather, natural disasters, and luck), measurement errors, and other statistical noise. The term u is a one-sided $(u \geq 0)$ efficiency component that captures the technical inefficiency of the farmer. It measures the shortfall in output Y from its maximum value given by the stochastic frontier $f(X_i;\beta) + \upsilon$. Although u can also assume exponential or other distributions, the half-normal distribution is preferred for parsimony because it entails less computational complexity Coelli *et al.*, [10]; U is assumed to be IID half-normal $[U \approx N(0, \sigma_\vartheta^2)]$. The two components v and u are assumed to be independent of each other. $|u_i| > 0$ reflects the technical efficiency relative to the frontier. $|u_i| = 0$ for a firm whose production lies on the frontier and $|u_i| > 0$ for a firm whose production lies below the frontier. Hence the technical efficiency of the farmer will be expressed as

$$\begin{aligned} TE_i &= Y_i / Y_i * \\ &= f\left(X_i;\beta\right)\exp\left(V_i - U_i\right) / f\left(X_i;\beta\right)\exp V_i \\ &= \exp\left(U_i\right) \end{aligned} \quad (3)$$

According to Battese and Coelli [11], technical inefficiency effects are defined by;

$$U_i = Z_i\delta + W_i \quad (4)$$

$i = 1\ldots$ N

Z_i is a vector of explanatory variables associated with the technical inefficiency effects, where δ is a vector of unknown parameters to be estimated. W_i are unobservable random variables, which are assumed to be identically distributed, obtained by truncation of the normal distribution with mean zero and unknown variance σ^2, such that U_i is non-negative. According to Battese and Corra [12], the variance ratio parameter γ which relates the variability of U_i to total variability σ^2 can be calculated in the following manner;

$$\gamma = \frac{\sigma_\mu^2}{\sigma^2}$$

where $\sigma^2 = \sigma_\mu^2 + \sigma_\nu^2$

So that $0 \le \gamma < 1$.

If the value of γ equals zero the difference between farmers yield and the efficient yield is entirely due to statistical noise. On the other hand, a value of one would indicate the difference attributed to the farmers' less than efficient use of technology. The parameters are estimated by the maximum likelihood method following Baten *et al.*, [13]. Technical efficiency levels are predicted from the stochastic frontier production function estimation. Following Ojo [14], this study used the stochastic frontier production function using the flexible log linear Cobb- Douglas production function because it has static input-output combinations, it is easy to estimate and interpret but also requires estimation of few parameters.

A Tobit model was used to estimate the sources of technical efficiency, where a regression of the inputs and farm-specific characteristics as independent variables such as household size, land under tea cultivation, quantity of fertilizer applied, access to credit and whether the farmer has a contract with a factory against the efficiency scores to analyze the role of farm-specific attributes in explaining efficiency in production of crops as introduced by Tobin [15], and it's expressed as follows:

$$Y^* = X\beta + \varepsilon \tag{5}$$

Where β is a vector of unknown coefficients, X is a vector of independent variables, and ε is an error term that is assumed to be independently distributed with mean zero and a variance of S^2. Y^* is a latent variable that is unobservable. If data for the dependent variable is above the limiting factor, zero in this case, Y is observed as a continuous variable. If Y is at the limiting factor, it is held at zero. This relationship is presented mathematically in the following two equations:

$$Y = Y^*$$

if $Y^* > Y_0$; $Y = 0$ if $Y^* < Y_0$ Where Y_0 is the limiting factor.

These two equations represent a censored distribution of the data. The Tobit model can be used to estimate the expected value of Y_i as a function of a set of explanatory variables *(X)* weighted by the probability that $Y_i > 0$. The coefficients for variables in the model, β, do not represent marginal effects directly, but the sign of the coefficient will give the researcher information as to the direction of the effect. According to Dadzie and Dasmani, [16], the use of ordinary least squares (OLS) regression to estimate determinants of *TE* is considered unsuitable because it might lead to biased estimates, given that *TE* scores are bounded between 0 and 1 and it's also affected by heteroskedasticity problem that is why the Tobit model was used to attain the third objective and deal with this problem.

The linear model was specified as shown below for each farmer.

$$TE = \beta X + \varepsilon \tag{6}$$

Where
TE = level of technical efficiency
X = Vector of explanatory variables
ε = Error term.

4. Empirical Results

Results presented in Table 1, indicate that tea contract out grower farmers allocated a bigger proportion of land for tea production (1.79 hectares averagely) as compared to the non-contract out growers who only allocated 1.11 hectares to tea production, it's also shown that there was a 5% significance difference between the mean of land allocated to tea production among these two categories of farmers.

Table 1. Mean difference in production parameters among contract out-grower and non-contract out-growers

Characteristics	Contract out-growers Mean (n=110)	Non-contract out-growers Mean (n=110)	Pooled sample (N=220)	t-value
Land under tea production (Ha)	1.79	1.11	1.45	-2.18**
	(2.938)	(1.427)		
Experience in tea production (Yrs)	23.01	18.64	20.83	-2.42***
	(14.355)	(12.338)		
Herbicide quantity used (Litres)	8.39	6.04	7.23	-2.23**
	(8.12)	(7.36)		
Total input cost (UGX)	660,750	477,567.9	570,855.1	-1.87**
	(659,513.7)	(327,933.2)		
Total labor cost (UGX)	1,468,264	984,667.3	1,225,361	-2.11**
	(2,031,415)	(1,278,136)		
Quantity harvested (Kg)	12,152.74	6,657.90	9,405.8	-3.01***
	(16,758.83)	(9,238.94)		
Output price (UGX/Kg)	363.91	401.91	382.91	1.42
	(11.25)	(280.62)		
Total revenue (UGX)	5,146,441	2,530,663	3,838,552	-2.39***
	(1.09e+07)	(3427737)		
Other enterprise income (UGX)	1,923,744	1,239,596	1,567,667	-2.78***
	(1,731,401)	(1,477,618)		

Source: Survey Data 2019. *, **, ***= Significance levels at 10%, 5%, 1% respectively. Figures in parentheses are standard deviations, UGX is Ugandan shillings and Kg is kilogram.

Furthermore, the results in Table 1 show that contract tea out growers on average had more experience of 23 years working in tea production compared with non-contract tea out growers who had 18 years of experience. The difference in years of experience is significant at 1%, this also implies that more experienced farmers are able to increase their yields since they know more methods or procedures of combating production risks. In addition, the results indicate that there was a significant difference in the total cost of inputs used (pesticides, herbicides and fertilizers) used in the production at 5% significant level.

Contract tea out growers incurred more input costs (660,750/=per ha) compared to non-contract tea out growers who used 477,560/= as total inputs cost. There was a 5% significance level difference between contract and non-contract tea out growers in terms of total labor cost incurred in the 2019 production season. Contract tea out growers spent 1,468,267/= compared to 984,667/= incurred by non-contract tea out growers. This difference in the labor costs can be explained by the fact that contract tea out growers own larger tea plantations in comparison to non-contract tea growers, this in turn calls for use of more man power/hired labor which increases the labor costs. Furthermore, contract tea out-growers incurred labor cost of 820,260.89/= per ha while non-contract tea out growers incurred 887,087.39/= per ha.

The use of more fertilizer, herbicides and more experience in tea production may be a reason as to why contract tea out growers had a significantly higher mean quantity of green tealeaf harvested per season. The difference in the quantity of green tea leaf harvested was significant at 1% level with a total harvest of 12,153kg per ha and 6,658kg per ha produced by contract tea out growers and non-contract tea out growers respectively. The results indicated no significant mean difference between the selling price received by contract tea out growers and non-contract tea out growers. In addition, contract tea out growers harvested 6,789.4kg per ha compared to 5,998.2kg per ha harvested by non-contract tea out growers which implies that on per hectare basis a contract farmer is spending less yet producing more tea leaves than a non-contract farmer.

The unit price of green tea leaf sold by contract tea out growers was 364/= per kg while non-contract tea growers fetched 402/= per kg from the sale of green tea leaf. The small difference of 38/= per kg in the unit price of green tea leaf is used as an attracting factor for the non-contract tea out growers to sell their tea to private tea dealers on a cash basis instead of selling the tea to the factories. On the other hand, contract tea out-growers were attracted into entering contracts with factories to sell them tea due to incentives like extension services, inputs like fertilizers, pesticides and herbicides at reduced prices and sharing dividends at the end of the year.

In addition, although non-contract tea out growers sold their green leaf at an assumed higher price, contract tea out growers generated more revenue from selling green tea leaf realizing an average of 5,146,441/= compared to 2,530,663/= generated by non-contract tea out growers. The difference in revenue generated from the sale of green tea leaf was significant at 1%. This can be attributed to the large land size allocated to tea production by contract tea out growers and their high use of fertilizers and herbicides thus raising the production of their plantations.

In the 2019 production season, the difference in income from other enterprises was significant at 1% level. Contract tea out growers earned 1,923,744/= from other enterprises a part from tea as compared to 1,239,596/= earned by non-contract tea out growers. This may be due to the fact the contract tea out growers earn more from selling green tea leaf thus investing the income in other enterprises such as cassava and coffee production, implying that contract tea out growers are more resource endowed than their counterparts.

Table 2. Maximum Likelihood estimates from the Cobb-Douglas stochastic frontier production model

Quantity of tea harvested (Y) = Dependent variable				
Independent variables	**Coefficient**	**S.E**	**Z**	**P-value**
Type of tea grown	0.05	0.037	1.50	0.135
Fertilizer quantity	0.25***	0.042	5.89	0.000
Land under tea	0.55***	0.047	11.77	0.000
Herbicide quantity	0.28***	0.047	5.86	0.000
Dummy (Extension access =1)	-0.15*	0.078	-1.89	0.059
Dummy (Contract =1)	0.18**	0.077	2.33	0.020
Constant	8.21***	0.117	69.91	0.000
Sigma_v	0.29	0.04		
Sigma_u	0.42	0.08		
Sigma2	0.27	0.05		
Lambda	1.45	1.11		
Gamma	0.69			
Log likelihood = -102.80				
Wald chi2(6) = 1313.45				
Number of observations (n) = 220				
Prob> chi2 = 0.000				

Source: Survey Data 2019. **, ***= Significance level at 5% and 1% respectively.

Table 3. Frequency distribution of Technical Efficiency of contract and Non-contract out-growers

Technical efficiency (%)	Contract out-growers (n = 110)	Non-contract out-growers (n=110)	Overall (N=220)
<39	0.91	3.64	2.27
40 – 49	0.91	3.64	2.27
50 – 59	10	10.91	10.46
60 –69	18.18	22.73	20.46
70 –79	45.45	32.73	39.09
80 –89	21.82	25.45	23.64
90 –99	2.73	0.90	1.82
Total	100%	100%	100%
Efficiency summary			
Mean 0.60			
Minimum 0.26			
Maximum 0.93			

Source: Survey Data 2019.

The results indicated that, the minimum and maximum technical efficiency score of small-scale tea framers where 26% and 93% respectively, the mean for technical efficiency for these farmers was estimated at 60%. The study further revealed that on average 70% of contract tea out-growers and 59.1% of non-contract tea out-growers attained over 70% technical efficiency level. The difference in the technical efficiency levels of operation is attributed to incentives given to contract tea farmers like fertilizers, herbicides and extension services. Approximately; 11.8% of contract out-grower famers and 18.2% of non-contract out-growers tea farmers operated below 60% technical efficiency levels. In addition, 7.3% of non-contract out-growers operated below 50% while only 1.82% of their counterparts operated below 50% technical efficiency level. This confirms the positive impact of incentives given to contract tea out-growers by the factories.

Table 4. Difference in technical efficiency levels of Contract and Non – Contract tea Out-growers

Group	Sample size	Mean efficiency	Standard Error	Std Deviation	t– value
Contract	110	0.74	0.013	0.132	
Non-contract	110	0.70	0.009	0.103	t = -2.1224**
Combined	220	0.72	0.008	0.119	

There is significant difference in technical efficiency scores between contract and non-contract tea out-growers. Contract tea out-growers had a higher level of mean technical efficiency (74%) than the non-contract tea out-growers (70%). The results show an overall efficiency of the whole sample at 72%. The results in Table 4 also shows a slight difference in the means of technical efficiency between these two categories of farmers, this can be explained by the impact of incentives like fertilizers and extension services provided to contract tea out-growers compared to their counterparts.

Table 5. Determinants of Technical efficiency among small scale tea farmers

TE scores (Y) = Dependent variable **Independent variables**	Coefficient	S.E	t – values	P-values
Age of farmer	-0.08***	0.03	-2.72	0.007
Age squared	0.06	0.09	0.71	0.482
Land under tea	-0.06***	0.01	-5.10	0.000
Fertilizer quantity	0.06***	0.01	5.27	0.000
Off-farm income	-0.002**	0.001	-2.11	0.036
Dummy (contract out-grower = 1)	0.01	0.02	0.52	0.607
Dummy (Credit Access = 1)	0.03*	0.02	1.76	0.081
Type of tea grown	0.02	0.01	1.46	0.145
Constant	0.93***	0.11	8.43	0.000
Number of observations = 220				
Log likelihood = 177.96				
LR Chi2(8) = 51.86				
Prob> Chi2 = 0.0000				

Source: Survey Data 2019 *, **, ***= Significance levels at 10%, 5%, 1% respectively.

The farmer's age squared had a negative sign was significant at 1% showing that a one-unit increase in age reduced technical efficiency by 0.08 and which led to the rejection of the third null hypothesis of this study and concluded that age of the farmer was a determinant of technical efficiency. This is probably because after a certain age interval it will have negative effect on efficiency because older farmers are thought to be more conservative in implementing modern technologies. This means that age and efficiency have inverted u-shaped relationship. That is to say; efficiency increases with age up to some point and then decreases with rise in age. Hence, middle aged farmers are more efficient than old aged and younger farmers. Since farming like any other profession needs accumulated knowledge, skill and physical capability, age of the farmers is decisive in determining efficiency. The knowledge, the skills as well as the physical capability of farmers is likely to increase as age increases. However, this tends to decrease after a certain age level. Older farmers have less physical capacity to undertake their farming activities efficiently. This finding is consistent with work of Chirwa [17] and Asefa [18].

The size of land allocated to tea production also a negative sign and was significant at 1 % level a one unit increase in the land under tea would lead to a decrease in technical efficiency by 0.06, this implies that size of land allocated to tea negatively influences technical efficiency. This can be explained by the theories of intensification that as farm size reduces the level of optimization increases and the reverse is true thus explain the negative sign of land under tea production. These results are in contrast with Kaiser, [19], Sharma *et al*., [20] and Chiona, [21] who argue that farm size had a positive relationship with efficiency and an increase in the size of the field would significantly increase the level of technical efficiency.

In addition, the result also revealed that the quantity of fertilizers used had a positive sign and was significant at 1%, this implied that a one unit increase in quantity of fertilizer used resulted into a 0.06 increment in technical efficiency among the tea farmers. The significance of the variable led to rejection of the third null hypothesis of this study and concluded that the quantity of fertilizer used is a source of technical efficiency. This is because use of fertilizers is expected to increase productivity and a farmer endowed with fertile land will be more technically efficient than those using infertile soils. Kyei *et al*., [22] who in their analysis of factors affecting the technical efficiency of cocoa farmers in the Offinso district -Ashanti region, Ghana found that fertilizer application had a positive and significant impact on efficiency.

Off-farm activity was negative and significant at 10% level of significance, revealing that a one unit increase in off-farm activities would reduce technical efficiency by 0.002. This implies that off/non- farm activities has a systematic effect on the technical efficiency of farmers. This is because farmers may allocate more of their time to off/non- farm activities tend to lag behind in agricultural activities. On the other hand, incomes from off/non-farm activities may be used as extra cash to buy agricultural inputs and can also improve risk management capacity of farmers. However, the result shows that agricultural lag effect of off-farm activity has dominated its income effect. This result is consistent with other empirical studies like Kibaara [23], Obwona [24] and Chirwa [17].

Contract tea out-growing was found not to be significant at any level but positively affected technical efficiency thus implying there is a positive contribution of factories contracting small scale tea farmers on their production efficiency. These results match with Sentumbwe's [25] and Kibirige's [26] who also indicated that farmers who got training in better agricultural practices were more technically efficient than those that had not participated and this can be attributed to their ability to easily adopt new technologies and pieces of advice to enhance productivity and efficiency.

Generally, credit is an important requirement for farmers who are cash constrained and unable to acquire farm inputs; households who have got access to credit are more efficient than their counter parts. In this study, access to credit was found to have positive and significant effect (at 10% level of significance) on farmers' technical efficiency in production, with a one unit increase in access to credit leading to a 0.03 increment in technical efficiency. This implies that credit availability shifts the cash constraint outwards and thus enables farmers to make timely purchases of inputs that they cannot otherwise afford from their own resources and enhances the use of agricultural inputs that leads to higher efficiency. These results are consistent with empirical studies by Kinde [27] and Gebrehawaria [28] who indicated that access to credit empowered farmers to purchase inputs and improve productivity.

5. Summary and Policy Implications

The sources of technical efficiency which indicated that: age squared of the farmer; land under tea production and off-farm income had a negative sign which indicated that an increase in the use of these variables would result into a reduction in technical efficiency levels of the farmer. Yet, the quantity of fertilizer used, dummy (access to credit =1), age of farmer, type of grown and dummy (contract out-grower =1) showed a positive sign in the results implying that an increase in the use of these variables by the farmer would lead to an increase in technical efficiency levels of the small-scale tea farmer. The study also revealed a significant difference in the technical efficiency score between contract and non-contract tea out-growers.

From the study two policy implications were attained, first the positive and higher elasticity of convectional inputs like fertilizer and type of tea grown indicate the importance of traditional inputs in subsistence agriculture. This Implies that enhanced access and better use of these conventional inputs could lead to higher crop production. Therefore, policy makers should make further efforts in strengthening financial institutions like micro finance and other arrangements that can relax farmers' liquidity constraints and help them afford traditional inputs. Secondly, the contribution of type of tea grown in improving efficiency is also evident in this study. This would justify introducing improved clone tea variety seedlings that not only reduce inefficiency but also increases revenue of tea farmers because they are high yielding.

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