INNOVATIONS

Analysis of Smallholder farmers coffee production efficiency in the Gedeo zone of southern Ethiopia

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Abstract

Despite coffee being considered a strategic crop in Ethiopia, its production system is attributed to low productivity, an average of 6(six) qt/ha, far from the potential. Moreover, in most developing countries like Ethiopia, resource reallocation and new technology creation and adoption are impossible; improving agriculture production efficiency remains the only reasonable option to increase productivity. This study, therefore, focused on the technical efficiency of smallholder farmers in Gedeo zone, one of the major coffee-producing areas in southern Ethiopia. Data were mainly collected from 205 coffee farmer households through a survey in 2021 and analyzed using the FRONTIER 4.1 application. In addition, the Cobb-Douglas stochastic production was estimated. As a result, it revealed that the mean technical efficiency of the sampled coffee farmers is 62%, with maximum and minimum efficiency scores of 82% and 20%, respectively. Finally, a Tobit regression was employed to analyze the determining factors of the coffee production technical efficiency and resulted in the household education level, the farm soil fertility, size of a coffee farm and the farmer's frequency of extension contacts were important significant factors to determine the farmers coffee production technical efficiency in the study area.

Keywords: 1. Cobb-Douglas 2. Stochastic frontier analysis 3.Technical efficiency 4. Smallholder 5.Gedeo

Introduction

In Ethiopia, the agriculture sector contributed about 36.3% to the gross domestic product (GDP), employed 75% of the total population and generated 70% of the foreign exchange. The share of coffee in the countries total export earnings accounted for 28.7%. More than 6 million smallholder farmers, principally producing for subsistence employing low-yielding farm techniques with barely any improved varieties, are responsible for 95% of the total coffee production. Moreover, it is a mainstay for more than 25 million people in its value chain, and thus, it's the country's most important strategic crop (NBE, 2019).

Coffee, the world's most traded commodity, is produced mainly by smallholder farmers in more than 50 countries. Ethiopia is considered the birthplace of coffee and is Africa's largest and fifth globally in coffee production. Concerning this, its production system is conventionally divided into four: forest coffee (wild coffee), semi-forest coffee, garden coffee, and large-scale plantation coffee (GAIN, 2014).

In a strive to achieve vision 2025, becoming one of the middle-income countries, the agriculture sector is considered the dominant source of capital for accelerating economic growth in the current economic policy of Ethiopia (mofed, 2010). To this end, the country has been implementing a series of strategies to achieve structural change in the economy led by agriculture sector transformation. However, despite the efforts made, the agricultural sector has not produced enough food to support the rapidly increasing population and didn't help reduce poverty among the rural households. Therefore, achieving agenda 2025 could be very cumbersome given the current structure of the country's subsistence rain-fed agriculture-dependent economy. In general, agriculture in Ethiopia is .best explained by its low productivity and less value-added production system.

In most of the developing countries, including Ethiopia, rural poverty surpasses urban poverty. In this context, the agriculture sector could play a very important role in any attempt to reduce poverty. But if the existing production system is not efficient, new technologies could not bring the expected improvements in the productivity of coffee. On the other hand, given the existing technology, improvements in technical efficiency will enable smallholder farmers to produce the maximum possible output from a given level of inputs. Hence, improvements in technical efficiency will increase productivity (Assefa *et al*., 2019).

The availability of data on farm-level technical efficiency is poor, and farmer knowledge on what and how to produce is sparse, especially in Sub-Saharan Africa. Moreover, since most developing countries like Ethiopia lack the financial capacity to invest in new agricultural technologies, increasing farmer technical efficiency is essential, implying plenty of room to boost agricultural productivity and production with existing resources.

Therefore, from the perspective of formulating effective agricultural policies, undertaking research to generate empirical data on farm level technical efficiency has paramount importance for providing valuable information to policymakers that will be used to enhance coffee productivity. Equally important is to examine the principal factors that affect farmers' technical efficiencyin coffee production since appropriate public policies can influence these factors. Unfortunately, in the study area, there is a lack of pertinent research on the technical efficiency of the smallholder farmers coffee production and the determinants of the variability in the efficiency levels among farmers. Therefore, this study aims to assess and analyze the farmers' technical efficiency and bridge the prevailing information gap on factors contributing to efficiency differences in coffee production.

This study has two principal objectives: the first is measuring coffee producers technical efficiency score, and the second is identifying major factors determining the technical efficiency of the smallholder coffee producers in the Gedeo zone, southern Ethiopia.

Methodology

Study area

Gedeo Zone is located in the southern region of Ethiopia, with a total area coverage of 1354 km^2. It is one of the 14(fourteen) administrative zones in the region. Astronomically it is located between 5^{0}50''26' to 6^{0}12''48' N latitude and 38^{0}12''48' to 38^{0}13''02' E longitude.

Gedeo Zone, with estimated 1077152 inhabitants, is a highly densely populated area. The mean annual rainfall and annual temperature range between 1001 - 1800mm and 12.6 - 22.5^{0}C, respectively. Since agriculture, specifically coffee production, is the mainstay for the farmers in this area, Gedeo is one of the principal coffee-producing areas in Ethiopia. Moreover, the well-known speciality coffee brands of "*Yirgacheffe*" and "*Kochere*" originated from this place.

Sampling and data

The sample frame was a list of smallholder coffee producers mainly living in selected *kebeles*[1], and three-stage sampling techniques were employed ultimately to select them. First, two districts[2], namely *Yirgacheffee* and *Dilla-zuria*, were selected from the Gedeo zone purposively based on the volume of coffee production, agroecology and its convenience. Secondly, six *kebeles* were selected randomly and proportionally from each of the sampled two districts. In the final stage, 205 smallholder coffee producers were selected using a simple random sampling technique for the survey.

Both the primary and secondary data types were collected for this study. The primary data were collected on pre-identified important variables that could help to explainfarmers socio-economic structure and coffee production efficiency employing semi-structured and pre-tested questionnaires. On the other hand, the secondary data were collected through a review of pertinent reports and documents of different institutions.

Data analysis

Both descriptive statistics and econometrics data analysis techniques were used to address the study objectives.

The descriptive statistics were conducted through mean, frequency and percentage analysis. It was used mainly to describe the socio-economic, demographic and institutional characteristics of the sampled smallholder coffee farmers.

The econometric analysis of agricultural efficiency measurement is intimately linked with the frontier production functions. According to Farrel (1957), the frontier analysis is classified into Parametric and non-parametric techniques based on its functional form adopted. Following the works of Farrel (1957), Eigner*et al.* (1977) and Meeusen and Van den Broeck(1977) proposed a stochastic frontier approach (SFA), and Chanes*et al.* (1978) proposed data envelopment analysis (DEA).

Since the DEA approach neither specifies a functional form nor includes assumptions about the disturbance term distribution, this study uses stochastic frontier model analysis to measure coffee production efficiency. In the stochastic frontier approach, disturbance term specification captures noise, measurement error and exogenous shocks beyond the control of the coffee farmer.

Therefore, following Cobb-Douglas functional form, the stochastic frontier production model for this study is specified as follows:

$$\text{Ln}\, Y_i = \beta_0 + ln \sum_{j=1}^{5} \beta_i\, \chi_{ij} + \varepsilon_i \qquad (1)$$

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[1] It refers to the lowest administrative rank in Ethiopian government structure.
[2]Gedeo zone is administratively divided into 6(six) districts, these are *Yirgacheffe, Dilla-zuria, Kochere, Bule, Gedeb and Wonago.*

Where ln is natural logarithm; i represented i^{th}Farm household; Y_iIs coffee produced of i^{th}Farm household measured in quintals; χ_{ij}Stands for the inputs variable; ε_iIs the residual random term where $\varepsilon_i = \nu_i - \upsilon_i \nu_i$Is symmetric component permits variation in output due to error and υ_iIs technical inefficiency relative to stochastic frontier). The maximum likelihood estimation can be used to estimate β, $\sigma = \sigma_v^2 - \sigma_\upsilon^2$And $\gamma = {\sigma_\upsilon^2}/{\sigma^2}$In the stochastic production function. $0 \leq \gamma \leq 1$; if $\gamma = 0$indicates deviation due to inefficiency and if $\gamma = 1$ indicates deviation due to noise.

Measurement of technical efficiency may not be an end by itself. More so, it reinforces the need to determine what factors influence it.Therefore, aregression model has been used to identify the socio-economic determinants of technical efficiency using the censored Tobit model.This model was employed because of the bounding nature of efficiency between zero and one (Johansson, 2006b). It is estimated as follows:

$$Y_i = \begin{cases} 1 \; if \; y_i^* \geq 1 \\ y_i^* \; if \; 0 < y_i^* < 1 \\ 0 \; if \; y_i^* \leq 0 \end{cases} \qquad (2)$$

Where, y is the measure of efficiency score of technical, allocative and economic efficiencies

y_i^*Is the unobservable latent variable

x_i'Are explanatory variables that determine farmers efficiencies

β_iAre parameters of the explanatory variables to be estimated

ε_iIs the random error term

Description of variables

Variables in the stochastic production function include:

Coffee output: it is used as a dependent variable representing the coffee yield in kilograms.

Coffee cultivated land size: it is total hectares of farmland allocated for coffee plantations.

Labour: person-day converted into total hours of family and hired labour in production.

Seedling: it is the coffee seedling planted by the farmer in the previous year.

Irrigation: it represents the frequency of the farmer’s use of irrigation.

Fertilizer: it is the volume of organic fertilizer application in kilograms.

i. Variables inthe Tobit regression analysis include:

Efficiency score: it is the dependent variable in this model.

Explanatory variables include:

Age:this variablerefers tothe age of the household head measured in years, and it is included as a proxy variable for the experience; thus, it is hypothesized to have a positive effect.

Education level: represents the household head formal education level measured in years and hypothesized to have a positive effect.

Gender: this variable indicatesthe sex of the household head 1=male and 0=female, and since farming is more of physical work in the study area, male heads are hypothesized to affect positively.

Family size: this is the number of family members in a household and hypothesized larger family has a positive impact.

Coffee cultivated land size: this variable is the total hectares of farmland allocated for coffee plantationsand is assumed to impact positively.

Fertility: it is a dummy variable representing the farm plot fertility status as 1=fertile and 0=otherwise. It is hypothesized positive.

Extension contacts: it is the frequency of farmers contact with extension workers and hypothesized positive.

Hypothesis testing

In a study using statistical models, it's highly recommended to testdifferent hypotheses on the parameters to make sure we choose the appropriate function to explain variables relation best and estimateour production function, efficiency score and factors affecting the farmer's technical efficiency employing the right estimation technique. Moreover, one of the advantages of stochastic production frontier (SPF) is it permits parameters diagnostic tests using maximum likelihood test ratio (Table 1).

Therefore, the general likelihood ratio (LR) statistics[3] were employed to make a hypothesis test on parameters of the stochastic frontier model estimated and it is specified as follows:

$$LR = -2[lnL(H_0) - lnL(H_1)] \quad (3)$$

Where; $L(H_0)$ is log-likelihood function values under the null hypothesis and $L(H_1)$ log-likelihood function values under the alternative hypothesis, and ln is the natural logarithm

Table 1: Hypothesis Test for the parameters in the stochastic production function

Null hypothesis	Calculated χ^2 (LR) value	Critical value (χ^2, 0.01)[4]	Decision[5]
$H_0: \gamma = 0$	45.44	6.635	Rejected
$H_0: \upsilon_i = \delta_0 = \delta_1 = \delta_2 \dots \delta_7 = 0$	84.64	16.812	Rejected

Source: own computation on survey data

The first tested null hypothesis ($H_0: \gamma = 0$) indicated that the efficiency effect in the stochastic production function was not stochastic, but it was rejected at a 1% level of significance. Thus the ordinary least square (OLS) estimation that gives an average value don't represent the data, but the stochastic function does. The second null hypothesis states that the regressors couldn't significantly explain the efficiency variation (all are simultaneously zero), but this was rejected at a 1% level of significance, indicating the variables can explain the efficiency difference among the coffee farmers.

Result and discussion

Production function

The Cobb-Douglas stochastic production function was estimated for the survey data to analyze the coffee farmers technical efficiency in the study area. The significance of the value of sigma squared (σ^2)indicates the goodness of the fit and assumed distribution for the error term. Additionally, the value of gamma (γ) reveals that 49.5% of the variations in coffee production among the sampled farmers result from technical inefficiency. Moreover, the elasticity of the production function is represented by the sum of the coefficients, and the value is 1.11, which is greater than one indicating that the estimated production function experiences an increasing return; This means, in other words, there a room to maximize production with the existing inputs (Table 2).

[3] The test statistics is assymetrically distributed as a χ^2 (chi-square) random variable with degree of freedom equal to the number of restrictions (Coelli *et al.*, 1998)
[4]Critical alues are obtained from the chi-square distribution table.
[5] The decision rule is "Reject the null hypothesis if LR $>\chi_1^2$ (2α)" for a test size α.

All the coefficients are positive as expected, and except seedling variable, all others significantly affected the coffee production. Out of the estimated explanatory variables, the result also indicated that the production of coffee is highly responsive for the size of coffee cultivated farm size and application of organic fertilizers at a 1% significance level. Moreover, labour and irrigation schemes affected the production at 5% and 10% levels of significance, respectively.

Table 2: Thestochastic cobb-Douglas production function

Variables	Coefficients	Standard error
Coefficient	1.961***	0.710
Ln(coffeeland)	0.512***	0.076
Ln(seedling)	0.010	0.018
Ln(labour)	0.209**	0.087
Ln(fertilizer)	0.311***	0.785
Ln(irrigation)	0.068*	0.035
Sigma squared (σ^2)	0.430***	0.051
Gamma (γ)	0.495***	0.063
Log-likelihood function	-177.4	
Return to scale	1.11	

Source: own computation on survey data

Figure 1 below depicts the efficiency score of coffee production. The mean technical efficiency was 0.62 (62%) with a minimum 0.2(20%) and maximum of 0.87 (87%) values, which means coffee farmers could improve coffee output upto 38% on average only by taking appropriate measures to improve the efficacy of resource utilization at disposal.

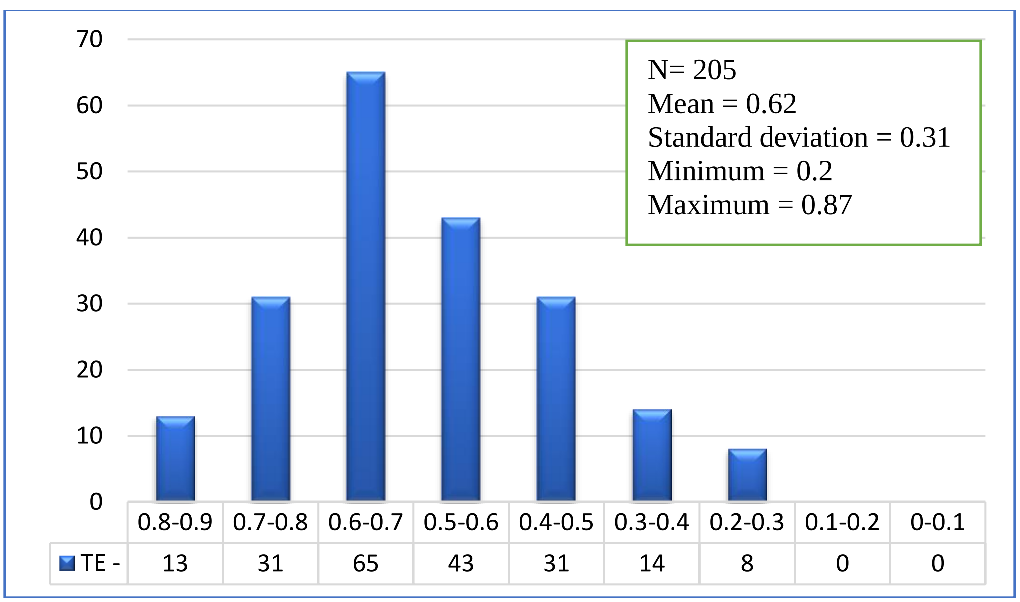

Figure 1: The technical efficiency score distribution
Source: own computation on survey data

Factors affecting technical efficiency

Since measuring the efficiency score is not enough to explain the farmer production system, the determining factors of an individual coffee farmer's technical efficiency were also estimated using the maximum likelihood technique. This analysis helps us know what factors determine the technical efficiency of the sampled coffee farmers in the study area. Therefore, different selected socio-economic explanatory variables were estimated against farmers efficiency scores.

The factors analysis result indicates that among those 7(seven) variables estimated in the model, 4(four) variables significantly affected the farmer's technical efficiency.

The variable household head education level is found positive and significant at a 5% level of significance. Since educated farmers believed to have the ability to access and analyze information regarding how to improve agricultural production efficiency, the result was expected. Endrias*et al*. (2013),Messay*et al.* (2013) and Elias *et al.* (2017) also found the same result in their studies.

The result of coffee farm size is found positive and significant at a 1% level of significance.

Table 3: Factors determining technical efficiency

Variables	Coefficients	Standard error
HH age	0.013	0.035
HHeducation	0.351**	0.153
HHgender	-0.112	0.018
Family size	-0.231	0.211
Areacultivated	0.020***	0.005
Soilfertilitystatus	0.150*	0.082
Extension contacts	0.110***	0.032
Constant	0.541***	0.053
Log-likelihood function	28.4	

Source: own computation on survey data

This study revealed that the effect of the size of coffee farmland is positive and significant at a 1% significance level. The result agreed with the prior argument that a larger farm size permits the farmer to apply different modern farm technologies simultaneously. However, the result also contradicts the study conducted by Tabi *et al*. (2017) and Assefa *et al*. (2019).

The coefficient of soil fertility revealed it positively affected the farmer's technical efficiency at a significance level of 10%, and the result coincides with the prior hypothesis. Therefore, the result implies that a farmer with fertile soil is more efficient than a farmer with poor soil fertility. Furthermore, the result is in line with the findings of Shumet (2012) and Hassen *et al.* (2014).

Finally, the effect of the variable for frequency of farmers contact with the extension workers was found to be positive and significant at a 1% level of significance; this result coincides with the study's prior expectation. Since extension service agents are agricultural production experts, they have a significant role in advising the farmers and transferring technology, which improves their technical production efficiency. The study conducted by Jema (2006) and Tadesse *et al.* (2017) also implied the same result.

Conclusion

This study examined factors of smallholder coffee farmers technical efficiency in the Godeo zone of southern Ethiopia. The stochastic frontier analysis method was adopted after the hypothesis test revealed that the average response production function couldn't represent the relation adequately. Therefore the stochastic Cobb-Douglas production function was estimated using the FRONTIER 4.1 computer application. The result also indicated the existence of a significant proportion of efficiency variation. Moreover, the result implied the existence of room for improving the farmer's technical efficiency upto 38% only by achieving maximum utilization of existing inputs.

The determinants of technical efficiency analysis estimated using the maximum likelihood technique confirmed that household head education level, coffee farm size, farm soil fertility and frequency of farmers extension contact exhibited a positive and significant effect at 5%, 1%, 10% and 1% respectively. Therefore, the government and research institutions should exploit these variables since these factors have important policy implications for mitigating coffee farmers' existing level of inefficiencyin the study area. Hence, development programs should exploit these variables.

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