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Technical Efficiency Analysis of Barley Producing Farmers in Ethiopia

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Abstract
The purpose of this study is to examine Technical Efficiency level of smallholder barley production and also to investigate socioeconomic determinants explaining the variation in Technical Efficiency among smallholder barley farmers using 488 random sample farm households in Ethiopia. The study employed Maximum Likelihood estimation technique and Cobb Douglas Stochastic Frontier Model that is one of the most commonly used models in most empirical studies of agricultural production analysis. And the study found that a one % increase in the input level of oxen-days, plot size, seed, and man-days respectively produce a return of 0.17, 0.22, 0.36, and 0.17 % increase in output, keeping all other factors constant. This implies that increasing the utilization of most of the productive inputs enhance the barley production. It is also found that age, gender, education, compost use, soil fertility status of barley plots, slope of the barley plots and distance of farmlands from residence affect technical efficiency of barley producers in Ethiopia. In general, the results show that there is the possibility to enhance the average plot level barley yield by 156% through increasing producers TE under the prevailing production input and the same production condition. Therefore, the concerned agricultural bodies should work hard towards improving barley farmers' technical efficiency in order to boost their productivity and production by optimizing the level of the inputs they are utilizing and by improving the aforementioned determinants.
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1. Background

Ethiopia is one of the least developed countries whose macroeconomic outlook has steadily posted robust growth over the past few decades. Nevertheless, the country is predominantly an agrarian society whereby agriculture accounts for 36 percent of the GDP while the service sector has almost equal contribution to the GDP followed by the industrial sector with 23 percent share. In addition, eighty percent of exports comes from agriculture that employs an estimated 75 percent of the country's workforce compared to less than 3% in the food secure developed countries. However, there are weak market linkages, recurrent drought and limited use of improved seeds, fertilizers and pesticides. Although, the sector faces all these challenges, agriculture-led economic growth that Ethiopia follows can bring about a long-lasting solution to Ethiopia's chronic poverty and food insecurity.

Agricultural production patterns vary markedly across Ethiopia according to agro-climatic conditions, in particular, widely varying rainfall and elevation. Five agro-ecological regions are distinguished in Ethiopia: moisture reliable cereal-based highlands, moisture reliable enset-based highlands, humid lowlands, drought prone highlands, and pastoralist area. Most smallholder farmers reside in the moisture reliable cereal-based highlands (i.e. 59 percent of total cultivated area). Farm area in the drought-prone highlands accounts for 26 percent of total area cultivated. With farmers using virtually no irrigation, reliable rainfall is an important condition to achieve good agricultural productivity. However, in the moisture-reliable enset-based highlands (11 percent of total farm area) population pressure has diminished farm size to such an extent that out-migration has become a major pathway out of poverty. Cultivation in the two other areas (humid lowlands and pastoralist area) is relatively less important, accounting for only 3.9% of all cultivated area in Ethiopia.

Barley is one of the cereal crops, domesticated about 10,000 years ago in the Fertile Crescent. Throughout the history, barley has undergone continuous manipulation in an effort to optimize its use for human consumption and an animal feed. Worldwide, barley is mainly produced for feeding and malting (Tadesse and Derso, 2019). Global barley production was about 170 million tonnes in 2018. Russia, Germany, France and others are major barley producers in the world. Ethiopia is the second largest barley producer in Africa. Crop production is dominant in Ethiopian agriculture, and the crop production in turn is cereal farming dominated. For instance, cereals production respectively constituted 81.2% and 88.4% of the total grain area and production in 2020/21 main cropping season because they are the principal staple crops (CSA 2020/21). Barley is one of the five principal crops with 0.93 million ha total cultivated area and 23.4 million quintals total production. It ranks fifth in cereal yield with 25.26 Qt/ha and it is the fifth cereal crop farming enterprise employing about 3.74 million smallholder cereal producers. (CSA 2020/21).

2. Theoretical framework

Conditional on the level of inputs and technology used by an individual farm, the ratio of the observed output to the corresponding frontier output is referred to as technical efficiency of the farm. Therefore, technical efficiency is defined as the amount by which the level of production for the farm is less than the frontier output (Kibaara, 2005). The extent of technical inefficiency designates an individual farmer's failure to attain the highest possible output level given the set of inputs and technology used. The production frontier denotes the highest possible output, using the available inputs and technology. Technical efficiency explains the difference between potential and observed yield for a given level of technology and inputs. Technical efficiency functions can be classified into parametric and non-parametric approaches. The non-parametric approach include Data envelopment analysis (DEA) and the free disposal hull (FDH) while the stochastic frontier approach (SFA), the thick frontier approach (TFA) and the distribution free approach (DFA) are the parametric approach. Mostly the assumptions made about the functional form, whether random errors have been accounted for, and the probability distribution assumed for the inefficiency distinguishes these approaches. Another essential distinction is between deterministic and stochastic frontiers where Deterministic models presume that any deviation from the frontier function is due to inefficiency (Thiam et al., 2001). This approach, overlooked circumstances beyond the control of the farmers, such as weather conditions, which could affect efficiency. The theory and specification of technical efficiency measures are shown in Aigner et al. (1977), and Meeusen and Van den Broeck (1977), who independently proposed and developed models which are thought to adjust some drawbacks in the deterministic frontier approach of estimating efficiency. In the stochastic frontier approach, the error term consists of two components, one being random and the other being a one-sided residual term denoting inefficiency. The stochastic production function which incorporates effects of inefficiency and exogenous shocks is given by the following equation.

$$Y_i = f(x;\beta) * \exp(v_i - u_i), where\ v_i >= 0, u_i \leq 0,$$

Where, Y_i- represents output from firm i, $\beta\ is$ vector of model parameters to be estimated, x is vector of inputs used in the production process, $f(x;\beta)$is a true representation of a farm production function, u_i is non negative random variables capturing technical inefficiency assumed to be NIID (0, σ^2_u) and v_i is random variable reflecting effect of statistical noise.

Estimation of Production Function

Cobb-Douglas Stochastic Frontier Model was fitted to estimate farm level technical efficiency and the associated efficiency score. The fitted log transformed Cobb-Douglas Stochastic Frontier model is described as follows.

$$Y_i = \beta_0 + \sum_{j=0}^{n} \beta_i\, lnX_{ij} + V_i - U_i$$

where ln represents the natural logarithm; n denotes total number of input variable included in CD; j represents inputs used; i represents the i^{th} barley plot in the sample; Y_i represents the actual output of the i^{th} barley plot; X_{ij} denotes j^{th} input variables applied in the i^{th} barley plot; β stands for the vector of unknown parameters to be estimated; The symmetric component (v_i) is assumed to be independently and identically distributed as N (0, σ^2_v). On the other hand, u_i captures the technical inefficiency of the farmer.

Maximum Likelihood estimation technique was used to estimate the model parameters $\beta_i's$ and the stochastic and the efficiency model variances $(\sigma^2 = \sigma_u^2 + \sigma_v^2)$ and $\gamma = \frac{\sigma_u^2}{\sigma^2}$ respectively. Following the estimation of the variances, producer's technical efficiency was estimated using Jondrow *et al*. (1982) approach given below.

$$E[u|v-u] or\ E[u|v+u]\ or \left(\hat{E}(u|\varepsilon) = \frac{\sigma\lambda}{1+\sigma^2}\left[\frac{f\left(\frac{\varepsilon\lambda}{\sigma}\right)}{1-F\left(\frac{\varepsilon\lambda}{\sigma}\right)} - \frac{\varepsilon\lambda}{\sigma}\right]\right), \varepsilon = v \pm u$$

Where f and F represent the standard normal density and cumulative distribution functions, respectively, and: $\lambda("signal\ to\ noise = \frac{\sigma_u}{\sigma_v})$. The fact that the estimated λ greater than 1 and significantly different from zero implies the presence of inefficiency effect within the model.

Based on Battese and Corra (1977) the existence of inefficiency was also tested using γ $(\frac{\sigma_u^2}{\sigma_u^2 + \sigma_v^2})$ parameter. It is interpreted as the percentage of the variation in output that is due to technical inefficiency. Likewise, the significance of σ_u^2 was tested to see whether the conventional average production function adequately represent the data or not.

Estimation of Technical Efficiency

The technical efficiency of individual barley plots is defined in terms of the ratio of observed output to the corresponding frontiers output, conditional on the level of input used by the plots. Hence the technical efficiency of the barley plots is expressed as follows.

$$TE_i = \frac{Y_i}{Y_I^M} = \frac{f(x;\beta) * \exp(v-u)}{f(x;\beta)\exp(v)} = \exp(-u)$$

Where $0 <= TE_i <= 1$, Y is the observed output of plot i and Y^M is the frontiers output. The technical inefficiency (Ui) could be estimated by subtracting TE_i from unity.

Determinants of technical efficiency

ML estimation is fitted in this study. It relates efficiency scores to selected producers' attributes that aims to identify determinants of technical efficiency. ML recapitulates the average relationship between the efficiency determinant factors considered and TE level based on the conditional mean function E(y|x). ML model fitted are shown as follows.

ML estimates were produced following one stage approach, which includes all inefficiency explanatory variables and conventional input variables simultaneously.

$$Ml: - - - lnY_i = \beta_0 + \sum_{j=0}^{n} \beta_j X_{ij} + \sum_{k=1}^{n} \sum_{\substack{j=1 \\ j\neq k}}^{n} \beta_{kj} X_{ik} X_{ij} + V_i - U_i + \sum_{i=1}^{m} \delta_i Z_{ik}$$

In the above equation, the term $\sum_{i=1}^{m} \delta_i Z_{ik}$ stands for the inefficiency determinants analysis. where, Z stands for k^{th} inefficiency explanatory, δ_i unknown parameters to be estimated.

3. Research sites, sampling and data collection

The study was conducted in Ethiopia including two districts each from Oromia, Amhara, SNNPR and Tigray regions, namely, Enemay and Shebel Berenta, Sinana, Gololcha, Gedebano, Gutazer, Wolene and Ofla which were selected purposively. The study use a national level data collected by EIAR in 2015 main cropping season. EIAR used stratified two stage sampling design for the study. The study districts were the stratums while each barley producing kebeles in the district form the primary sampling unit (PSU's). Barley producers in each kebele constitute the second stage sampling unit (SSUs). Using simple random sampling technique a total of 488 barley producing households were selected. Summary of descriptive statistics of major variables used in the econometric models is placed in the table below.

Table 1. Summary of descriptive statistics of major variables used in the econometric models

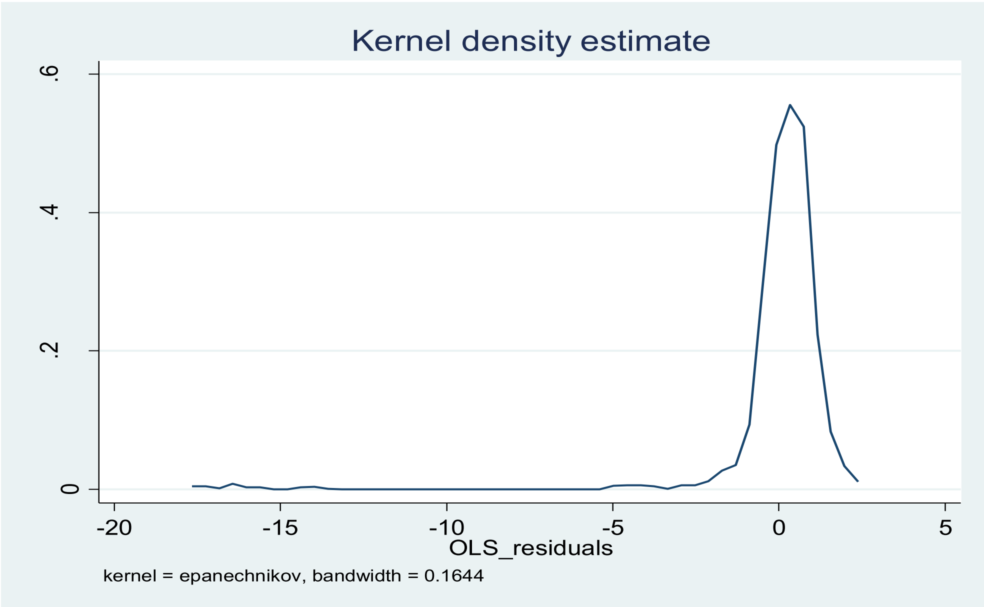
Variable	Variable description	Mean (Std.Dev)
Input and output variables		
YieldPH	*Productivity realized (kg/ha)*	1953.52 (1200.69)
Area	*Plot size in ha*	0.38 (0.30)
Fertilizer rate	*Fertilizer amount (DAP + UREA) in kg*	82.10 (105.80)
Socioeconomic characteristics		
AGE	Age of household head	45.75 (11.59)
SEX	Gender of household head (%) (male)	96
Distance	Distance from residence to plot	26.61 (26.04)
PlotSoilFer	Plot soil fertility status (%)	
	Good	33.22
	Medium	53.36
	Poor	13.42
PlotSlop	Cultivated plot slope (%)	
	slope (flat)	60.23
	Medium slope	33.88
	Steep slope	5.89
Compost	Compost application (%)	11.62

4. RESULT AND DISCUSSION

It is necessary to check for possible presence of multicollinearity using VIF test before fitting the stochastic frontier model. And the test result indicates that the data is free from multicollinearity problem (Table 2). The skewness of the OLS residuals from the fitted multiple linear regression model was checked in order to decide to use OLS or ML estimation methods before maximum likelihood estimation begins. Waldman (1982) has shown that when the OLS residuals have 'negative' skewness or similarly when the distribution of inefficiency term (u) is positively skewed the MLE for the frontier model is unique, and no trouble in estimation. For this study OLS residual was negatively skewed while inefficiency term estimated from the half normal stochastic CD production functions showed positive skewedness (Figure 1). As Waldman, the result obtained infers presence of TE in plot level barley production and appropriateness of stochastic frontier model for TE analysis in the study.

Table 2. Test for multicollinearity

Variable	VIF	1/VIF
logoxendays	8.67	0.12
logplotarea	7.23	0.14
logseed	3.17	0.32
logmandays	1.73	0.58
logfertilizer	1.06	0.94
Mean VIF	4.37	



Aigner, Lovell and Schmidt (1977), to validate the hypothesis, H_0:σ^2_u=0 vs H_A: $\sigma^2_u \neq 0$, to check whether the average production function (OLS) best fit the data or not, likelihood ratio test was utilized. Ho was rejected at 1% level of significance indicating appropriateness of the fitted CD Stochastic Frontier Production Function over the convectional production function which is estimated by OLS. This test result shows existence of significant TE variation among plots. Also, the estimated lambda (λ) value implies that the discrepancy between the observed and the maximum attainable plot levels output is dominated by variability emanating from the TE level the associated barley plots were managed. Over all significance test was employed to check if at least one of the conventional production inputs significantly affect the observed production output at 0.01 level of significance. The test performed ratified that there is joint significant effect of the productive factors. Thus, an individual effect of the productive factors on the technical efficiency level was evaluated via standard normal distribution test.

The estimated coefficients for all the productive factors in the model were positive. All the five inputs but fertilizer taken into account in the production function had a significant effect in explaining the variation in barley production among plots (Table 3). The estimated coefficients of land, labour, seed and oxendays were significant at 1% level of significance while the coefficient of fertilizer was insignificant. The result depicts that a one % increase in the input level of oxen-days, plot size, seed, and man-days respectively produce a return of 0.17, 0.22, 0.36, and 0.17 % increase in output, keeping all other factors constant. This implies that increasing the utilization of most of the productive inputs enhance the barley production.

Table 3 also shows the relationship between level of farmers' technical efficiency and the determinants of productivity variability emanated from TE difference among smallholder barley farmers in Ethiopia. The TE determining analysis takes into account demographic factors, (age, sex and education) and the biophysical and socio economic factors such as soil fertility, distance of farmland from residence, slope of the farmland, use of compost, and district. The Maximum Likelihood method estimated the parameters of the explanatory variables in the TE model, and the dependent variable of the model was inefficiency. The positive signs implied that an increase in the explanatory variable would increase the corresponding level of inefficiency, that is, deterioration of efficiency, and the negative sign is interpreted inversely. Table 3 depicts coefficients of TE model estimated by ML technique. TE effects of all the factors namely, age, gender, education, district, distance of farmland from residence, soil fertility, plot slope and compost use were significant.

All the districts in the study were more efficient than Enemay District. Besides, male farmers were more efficient than their counterparts. Age has a significant positive effect, at 1% level of significance, on inefficiency in the study area. That is, as age increases, barley producers are becoming less efficient as compared to their younger counterparts in the study area. Education has a direct relationship with inefficiency. The ML estimate for output effect of barley plots soil fertility status was found significant at 5% level of significance. The result inferred that there was direct relationship between barley producers TE level and their plots soil fertility status. That is, degraded farmlands are less efficient as expected apriori. This means, farmers with more fertile plots were technically efficient as compared to those who cultivate marginal lands, keeping all other factors constant. In addition, the ML estimates for effect of use of compost on inefficiency was found negative and significant at 1% level of significance. This means, those barley farmers who use compost had lower inefficiency as compared to those farmers who do not utilize compost in the study area. This indicates that compost utilization improves the efficiency of smallholder barley farmers, and, hence, their productivity and production. The ML result for effect of distance of plots on inefficiency was positive and statistically significant at 1%. That is, the longer the distance farmers travelled, the higher inefficiency faced by the barley farmer in the study area.

Table 3. Maximum likely hood estimates for Cobb-Douglas production function and the determinants

Iteration 15: log likelihood = -769.31012

Stoc. frontier normal/half-normal model Number of obs = 600

Wald chi2(5) = 502.64

Log likelihood = -769.31012 Prob > chi2 = 0.0000

logproduction	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
logproduction						
logoxendays	.1678857	.0769678	2.18**	0.029	.0170317	.3187398
logplotarea	.2191679	.0990573	2.21**	0.027	.0250191	.4133166
logseed	.3587256	.0556245	6.45***	0.000	.2497036	.4677477
logfertilizer	.0002718	.0031352	0.09	0.931	-.0058731	.0064167
logmandays	.1677942	.045636	3.68***	0.000	.0783493	.257239
_cons	5.155652	.3308868	15.58	0.000	4.507126	5.804178
lnsig2v						
_cons	-3.425957	.2892229	-11.85	0.000	-3.992824	-2.859091
lnsig2u						
District						
Shebel Berenta	-1.686393	.4256228	-3.96***	0.000	-2.520598	-.8521872
Sinana	-2.00735	.2584587	-7.77***	0.000	-2.51392	-1.500781
Gololcha	-3.823631	.2155839	-17.74***	0.000	-4.246168	-3.401095
Gedebano-Gutazer-Wolene	-1.920938	.2548631	-7.54***	0.000	-2.42046	-1.421415
Ofla	-2.329876	.2319868	-10.04***	0.000	-2.784561	-1.87519
Gender						
Male	-.5870425	.3086218	-1.90*	0.057	-1.19193	.017845
Age	.0170385	.0061725	2.76***	0.006	.0049406	.0291363
Education	.0977091	.0180016	5.43***	0.000	.0624266	.1329917
Distance	.0185885	.0029221	6.36***	0.000	.0128613	.0243158
Soil fertility Status						
Medium	.3659889	.1450973	2.52**	0.012	.0816034	.6503744
Poor	.2136336	.2295494	0.93	0.352	-.236275	.6635422
Plot slope						
Medium slope	.2126932	.1655903	1.28	0.199	-.1118578	.5372442
Steep slope	- .8991111	.2998965	-3.00***	0.003	-1.486898	-.3113247
Compost Use						
yes	-.6504352	.2349683	-2.77***	0.006	-1.110965	-.1899057
_cons	1.744268	.4177491	4.18	0.000	.9254945	2.563041
sigma_u	2.514022	.0724529	34.70	0.000	2.375953	2.660114
sigma_v	.1803279	.0260775			.1358218	.2394178
lambda	3.45e+07	.0724529	4.8e+08	0.000	3.45e+07	3.45e+07

***, **, * indicate significance at 1 percent, 5 percent and 10 percent level respectively.

The stochastic production frontier represents the maximum output which can be attained using a given vector of inputs, i.e. the technically efficient yield. Efficiency yield gap is the difference between the technically efficient yield and the actual yield (Silva et al. 2017). It indicates the extra yield that could be attained using the same level of inputs, when used optimally in the production. The efficiency yield gap computes the degree to which farmers could produce more by using the same inputs and the given technology, but with improved practices regarding the timing, placement and form of the inputs applied. On this study, the mean levels of the actual and potential yield during the production year were 19.54 Qt/ha and 50.13 Qt/ha. The actual and the potential mean yield were compared using paired sample t-test and the observed mean deference (30.51Qt/ha) was found significant at 1% level of significance (Table 4). The ratio of the average yield gap to the average actual yield shows the possibility to enhance the average plot level yield by 156% through increasing producers TE under the prevailing production input and the same production condition. In general, the result had underlined farmer's opportunity to boost their productivity by optimizing the level of the inputs they are using.

Table 4. Yield Gap analysis output

Variable	Mean	Std. Dev.
Average Fortier productivity (kg/ha)	5012.529	1942.252
Actual yield obtained (kg/ha)	1953.515	1200.686
Yield gap (kg/ha)	3050.917	1800.827

CONCLUSION and RECOMMENDATION

The ultimate purpose of this study is to identify the level of technical efficiency at which the barley plots are managed as well as to investigate their determinants in Ethiopia and, hence, put forward a recommendation. The study used Maximum Likelihood technique and Cobb Douglas production function that has been one of the most commonly used models in most empirical studies of agricultural production analysis. It is found that most of the productive factors are positive and significant. In general, a one % increase in the input level of oxen-days, plot size, seed, and man-days respectively produce a return of 0.17, 0.22, 0.36, and 0.17 % increase in output, keeping all other factors constant. This implies that increasing the utilization of most of the productive inputs enhance the barley production. It is also found that age, gender, education, compost use, soil fertility status of barley plots, slope of the barley plots and distance of farmlands from residence affect technical efficiency of barley producers in Ethiopia. The mean levels of the actual and potential yield during the production year were 19.54 Qt/ha and 50.13 Qt/ha. In general, the results show that there is the possibility to enhance the average plot level barley yield by 156% through increasing producers TE under the prevailing production input and the same production condition. Moreover, the result had underlined farmer's opportunity to boost their productivity by optimizing the level of the inputs they are using. Therefore, the concerned agricultural bodies should work hard towards improving barley farmers' technical efficiency in order to boost their productivity and production by optimizing the level of the inputs they are utilizing and by improving the aforementioned determinants.

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