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ANALYSIS OF LEVELS AND DETERMINANTS OF TECHNICAL EFFICIENCY OF WHEAT PRODUCING FARMERS: THE CASE OF EAST GOJAME ZONE, AMHARA REGION, ETHIOPIA

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ABSTRACT

This paper examines the technical efficiency of smallholder wheat producers in three districts of the Misrak Gojam zone of Amhara region, Ethiopia. Using two stage stratified simple random sampling design, 210 wheat producing households were randomly selected and studied. Cobb-Douglas Stochastic Frontier Model was fitted to estimate farm level technical efficiency and the associated efficiency scores. The analysis of technical efficiency determents was conducted employing both Maximum likelihood (ML) and quantile regression techniques (QR). The study findings has shown presence of strong inefficiency in the use of factors of production. Fertilizer amount, plot size, oxen days and seed rate has shown their positive contribution in enhancing farm level technical efficiency. In percentage terms, the estimated minimum, average and maximum efficiency levels were 26%, 78% and 97%. As this result implies, a farmer with the estimated average efficiency level has the opportunity to entertain 19% boost in his wheat production by improving his technical efficiency level to the level of his most efficient counterpart. In general, the result had underlined farmers opportunity to boost their productivity by increasing the level of the inputs they are using pertaining to the given production technology. Adoption of wheat rust mitigation intervention was demonstrated being a major determinant of efficiency across all estimated efficiency levels while household size and being model farmer have expressed their significant positive effect on the efficiency level of best performing (75th and 99th efficiency quantiles) farmers.

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INTRODUCTION

Ethiopia is the tenth largest country in Africa having a size of 1.1 million square kilometer. It is second most populous country in the continent with a population of about 107 million. Agricultural is the main driver of the economy manifested by making 34.9% of the national GDP, employing more than 80% of the population, and accounting 70% of the export earnings (MoFED 2018). By large, agriculture in Ethiopia is mainly subsistence, operated by more than 16 million household farmers who operates on one hectare or less. The country crop production is cereal farming dominated. For instance, in 2017/18, cereals were accountable for 81% (10.3 million hectare) of the grain cultivated area and 87% (268 million quantal) of the total grain production. Maize, teff, wheat and sorghum made up 70% and 74 % of the total cereals area and production respectively (CSA 2018). These four crops and barley together were accounted for 14 % of the total GDP in 2005/06 (Alemayehu 2012).

Though cereal production plays such an important role in the economy, challenges limit its potential contributions. Wheat is the fourth most important cereal cultivated in Ethiopia after teff, maize and sorghum, covering about 13.5% of the cereal area and 15.2% of the cereal production. About 4.2 million households were producing wheat with an average yield of 27.7qt/ha often under sub-optimal production environments (CSA 2017/18, Table 1). Two wheat species, bread (Triticum astivum L.) and durum (T. turgidum L.) wheat are grown in country. While bread wheat is a recent introduction, durum wheat is indigenous. It is clear that production inefficiencies are limiting agricultural productivity and the sources of such inefficiencies are diverse. A key requirement of improving smallholder farmers productivity is to use production inputs more efficiently. Understanding the production elasticity of inputs, efficiency, and socio-economic characteristics of the farmers that influence such efficiency would help to improve the design of agricultural policies interventions which could in turn help to increase food production.

This study aims to assess the technical efficiency of wheat producing smallholder farmers and determinants of efficiency in Misrak Gojame Zone of Amhara region, Ethiopia. The study used part of national level wheat production survey data collected in 2015 production year through joint Effort of International Center for Agricultural Research in the Dry Areas (ICARDA) and Ethiopia Institute of Agricultural Research (EIAR). The broad objectives of the study were, to examine the extent of farm specific technical inefficiency in the use of agricultural resources, and to determine the socioeconomic factors which affects production efficiency level.

Theoretical framework

Technical efficiency in crop production can be defined as a farmer's ability to maximize outputs given a set of inputs and technology. 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 the available inputs and technology, is represented by the production frontier. Technical efficiency explains the difference between potential and observed yield for a given level of technology and inputs. There are two approaches called deterministic frontier approach and stochastic frontier approach, to measure technical efficiency. The deterministic frontier approach, which assumes that any deviations from the frontier are due to inefficiency. This approach, ignored factors beyond the control of the farmers, such as weather conditions, which could influence efficiency. Aigner, Lovell, and Schmidt (1977) and Meeusen and van Den Broeck (1977) independently developed the stochastic frontier approach (SFA) to address some of the limitations of the deterministic frontier approach. In the new approach, the error term consists of two components, one being random and the other being a one-sided residual term representing inefficiency. The stochastic production function which incorporate 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, Yi– represent output from firm i, βvector of model parameters to be estimated, Xvector of inputs used in the production process, $f(x;\beta)$is a true representation of a farm production function, U_i - non negative random variable scapturing technical inefficiency assumed to be NIID(0, σ^2_u) and V_i- random variable reflecting effect of statistical noise. The technical efficiency of individual farmers is defined in terms of the ratio of observed output to the corresponding frontiers output, conditional on the level of input used by the farmers. Hence the technical efficiency of the farmer is expressed as follows.

$TE = \frac{Y_i}{Y_I^M} = \frac{f(x;\beta)*\exp(v-u)}{f(x;\beta)\exp(v)} = \exp(-u)$ where 0<= TE <=1, Y is the observed output of farm i and Y^M is the frontiers output.

RESEARCH AREA AND METHODOLOGY

Efficiency estimation: The wheat production system in the study area was assumed to follow Cobb-Douglas production function. Consequently 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.

$$Y_i = \beta_0 + \sum_{j=1}^{6} \beta_i\, lnx_{ij} + v_i - u_i,\ \ i = 1,\cdots,N\ and\ u_i \geq 0, \ldots..1$$

$$v_i \sim NIID(0,\sigma_v^2), u_i^2 \sim NIID(0,\sigma_u^2)$$

Where, Y_i - the total amount of wheat produced in kg by the i[th] farmer, β_i'sare model parameters to be estimated, X_{i1} - land sized used in meter square,, X_{2i} - the total number of oxen power used in oxen-days, X_{i3} - the total labor (family and hired) used in man-days, X_{i4} - the total quantity of seed used in kilogram, X_{i5} - the total amount of fertilizer applied in kilogram, U_i - non negative random variable scapturing technical inefficiency and V_i- random variable reflecting effect of statistical noise.

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.

$$E\left(\frac{u_i}{\varepsilon_i}\right) = \sigma^2\left[\frac{f\left(\frac{\varepsilon_i\lambda}{\sigma}\right)}{1 - F\left(\frac{\varepsilon_i\lambda}{\sigma}\right)} - \frac{\varepsilon_i\lambda}{\sigma}\right] - - - - - - - - - - - - -2$$

Where f and F represent the standard normal density and cumulative distribution functions, respectively, and: $\lambda("signal\ to\ noiseratio) = \frac{\sigma_u}{\sigma_v}$

Determinants of technical efficiency: Having production efficiency measure for each farm, one can identify those farmers who need intervention and corrective measures. Since efficiency scores vary across producers, they can be related to producer characteristics like ownership, gender, age, education, extension service, location, etc. Beside the Maximum likelihood (ML) estimation Quantile Regression Model (QR) that relate efficiency scores to selected producers' characters was fitted aiming to identify determinates of technical efficiency. Maximum likelihoods (ML) summarize the average relationship between a set of regressors and the outcome variable based on the conditional mean function E(y|x). This provides only a partial view of the relationship. But a more comprehensive picture of the effect of the predictors on the response variable can be obtained by using Quantile regression. Quantile regression models show the relation between a set of predictor variables and specific percentiles (or quantiles) of the response variable. It specifies changes in the quantiles of the response. QR is more robust to non-normal errors and outliers. The fitted QR regression model is presented as follows.

$$FE_i = \beta_0 + \sum_{i=1}^{8} \beta_i x_i + \varepsilon_i$$

Research sites, sampling and data collection: The study was conducted in three districts of the Misrak Gojam zone of Amhara region namely, Gozamen, Wonbrema and Debre Elias, which were selected purposively. Amhara region is the second largest wheat producer in the country with a share of about 30 and 26 percent of the crop national acreage and the associated production, respectively. Misrak Gojam zone is the region main wheat producer. For instance, in 2017 cropping season it was accountable for 23% of the region wheat production. Currently, wheat is the major livelihood base for 325868 households of the zone (CSA, 2017/18). Stratified two stage sampling design was used for the study. The three study districts were the stratums while each wheat producing kebeles in the district form the primary sampling unit (PSU's). Wheat producers in each kebele constitute the second stage sampling unit (SSUs). The list of wheat producing kebeles and households prepared by each district agricultural office was used as primary and second stage sampling frame. Using simple random sampling technique, two kebeles per district and 35 producers per sampled kebeles were selected. Totally 210 wheat producing households 70 from each district were randomly selected and studied. Summary of descriptive statistics of major variables used in the econometric models is the table underneath.

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

Variable	Variable description	Mean (Std. Dev)
Input and output variables		
Production	Output obtained in kg	1377(1041)
Plotsize	Plot size used in meter square	4345(2875)
Fertilizer	Fertilizer amount (DAP + UREA) in kg	125 (80)
Labor	Labor used in man days	31 (17)
Seed	Seed amount used in kg	78(48)
Oxendays	Number of oxen days	14(9)
Socioeconomic characteristics		
Wgyears	Wheat growing experience in number of years	19(10)
HHSIZE	Number of household members	6(2)
Pldistance	Distance from residence to plot in waking minuets	21(17)
Sex	Household head Sex (male=1)	0.97(0.53)
Mfarmer	Model farmer (model=1)	0.30(0.46)
Wrust	wheat rust mitigation activities (participation=1)	0.52(0.50)

RESULT AND DISCUSSION

Before maximum likelihood (ML) estimation begins, the skewness of the OLS residuals resulted from the regression of y on x was checked in order to decide the type of the stochastic frontier model to be adopted for the study. Waldman (1982) has shown that when the OLS residuals are skewed in the wrong direction, a solution for the maximum likelihood estimator for the stochastic frontier model is simply OLS for the slopes and for σ_v^2but zero for σ_u^2. It has been shown that when the OLS residuals have the '' negative" skewness or similarly when the distribution of inefficiency term (u) is positively skewed, then the ML for the frontier model is unique, and no trouble in estimation. In other word when they have the "wrong" skewness, it is only shown that the OLS results are a local stationary point of the log likelihood, not that they are the global maximizers. For our case as depicted in Figure 1, the distribution of the inefficiency estimate u is right skewed implying uniqueness of ML estimates of the frontier model. Also, the hypothesis H_0: σ_u^2 =0 was rejected at 0.001 level off significance implying indirectly the distribution of the OLS residual to be negatively skewed and this in turn entails appropriateness of ML estimates for the frontier model to be used (Table 1). Having these evidences, the inefficiency term for the problem under study is assumed to follow half normal distribution.

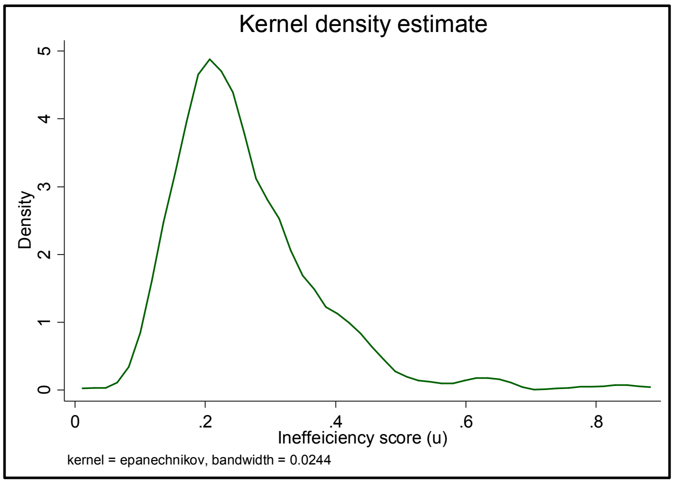

Figure 1. Kernel density for the inefficiency term of the SFM

Following Aigner, Lovell and Schmidt (1977), likelihood ratio test was used to validate the hypothesis, H0:$\sigma_u^2 = 0$ vs H0:$\sigma_u^2 \neq 0$, to see whether the average production function best fit the data or not. Ho was rejected at 1% level of significance implying appropriateness of the fitted Cobb-Douglas Stochastic Frontier Production Function over the convectional production function which is estimated by OLS. This test result, entails presence of significant technical inefficiency variation among plots. Also, the estimated lambda (λ) value (1.2) implies that the discrepancy between the observed and the maximum attainable levels output is dominated by variability emanating from technical inefficiency. Over all significance test was employed to see if at least one of the input variables significantly affect the observed production inefficiency at 0.01 level of significance. The test conducted confirmed joint significant effect of the productive factors. Consequently, individual effects of the productive factors on the technical efficiency level was assessed via standard normal distribution test.

All the estimated coefficients in the model for productive factors were positive. Out of the five inputs considered in the production function, four (land, seed rate, oxen power and fertilizer) had a significant effect in explaining the variation in wheat production among plots. The estimated coefficients for land and fertilizer were significant at 1% level of significance while the coefficient of oxen days and seed amount were significant at 5% level of significance (Table 1). Kaleb *et al* (2016) got in similar result in study conducted at country, Ethiopia, level. Also, Mages (2019) has found similar result except for significance of seed effect for similar activity conducted in Jamma district, Ethiopia. Solomon (2014) in his effort to establish technical efficiency of major crop production has found land, fertilizer and seed having positive significant effect in enhancing farmers technical efficiency. The positive coefficient for all parameters indicates that all the inputs have increasing retune to scale effect. The result entails that a one % increase in the input level of plot size, seed, fertilizer and oxen power respectively produce a return of 0.46, 0.12, 0.35 and 0.14% increase in output, keeping all other factors constant. In general, the result had underlined farmers opportunity to boost their productivity by optimizing the level of the inputs they are using.

Table 2. Maximum likelihood estimates for Cobb–Douglas production function

Variable	Coefficient	Z-value
Lnplotsize	0.46	7.39***
Lnlabour	0.04	0.83
Lnseed	0.12	2.52**
Lnfertilizer	0.35	7.36***
Lnoxendays	0.14	3.35**
Constant	10.11	36.64***
λ	1.21	24.34***
σ^2_u	0.12	8.03
σ^2_v	0.079	15.14
Log likelihood	-161.39	
N	451	

***, ** indicate significance at 1 and 5 % levels, respectively.

Table 3. Farm level technical efficiency by district

District	Mean	Minimum	Maximum	Quantiles		
				1st quantile	Median	3st quantile
Wonbrema	.78	.44	.97	.76	.80	.83
Debre Elias	.78	.26	.90	.74	.80	.83
Gozamen	.78	.43	.91	.73	.79	.86
Total	.78	.26	.97	.74	.80	.84

Table 4. Quartile regression and ML estimates compared

Variable	ML estimates		Quantile regression estimates							
			(25th)		(50th)		(75th)		(99th)	
	Coef.	t-value	Coef.	t-value	Coef.	t-value	Coef.	t-value	Coef.	t-value
Sex	0.0024	0.02	-0.037	-0.36	-0.014	-1.63	-0.0007	-0.08	0.031	0.52
Household size	0.0022	0.25	-0.003	-0.97	-0.001	-0.28	0.0025*	1.93	0.006**	2.28
Model farmer	-0.0332	-0.91	-0.006	-0.56	0.002	0.18	-0.0052	-0.93	-0.021**	-1.69
Relative in village leadership	0.0836**	2.24	-0.031*	2.4	-0.006	-0.62	0.0082	1.5	0.014	1.11
Wheat rust intervention	-0.0852**	-2.61	-0.031**	-3.13	-0.022**	-2.91	-0.0214***	-4.18	-0.050***	-3.58
Wheat growing experience	0.009	0.46	0.007	1.14	-0.002	-0.34	-0.0004	-0.13	0.005	1.2
Years of living in the village	-0.0127	-0.71	-0.003	-0.44	0	-0.06	-0.0043	-1.38	-0.005	-0.89
Plot distance	0.001	1.13	0.000	1.5	0	0.88	0.0002	1.28	0.000**	-1.85

Note: ***, ** and * indicate significance at 1%, 5 % and 10 % levels, respectively.
Negative signs of the ML coefficient indicate the variable have positive effect on technical efficiency and vice versa.
Negative sign of the quantile regression coefficient indicates the variable have negative effect on technical efficiency and vice versa.

The mean level of technical efficiency for the sample of plots is 0.78(78%), with a standard deviation of 0.085. This implies that, on the average, they could only achieve about 78% of the potential maximum output from a given mix of production inputs. The distribution of the efficiency score rages from 26% to 97% (Table 2 and Figure 1). This indicates that if the average farmer in the sample was to achieve the technical efficiency level of its most efficient counterpart, then the average farmer could realize a 19% increase in output by improving technical efficiency with existing technology. Farms in the three districts considered in the study were operating at similar average efficiency level. For the least operating 25% of the farms the optimum efficiency level was 74 % while for best operating similar proportion of farms the minimum efficiency level was 84%. The remaining 50% of the farms were operating with efficiency level which ranges from 84 to 97%. Quantile regression analysis was conducted to compare how some percentiles of the technical efficiency may be more affected by certain socioeconomic characteristics than other percentiles. Coefficient estimates for the 25, 50, 75 and 95th quantile regression, and the ML estimates for technical efficiency are presented in Table 3. Household head sex, wheat growing experience (years), number of years household lives in the village, whether or not relatives/friends in village leadership, whether or not the head is model farmer, household size, whether the household is beneficiary of wheat rust mitigation project operating in study area, wheat plot distance from residence, wheat plot soil fertility status and whether soil conservation practice conducted on the wheat plots farmed were the factors evaluated for significant effect on production efficiency level of wheat farmers. The ML estimate for the effect of household size on technical efficiency was insignificant, while the quantile regression estimates for the higher efficiency groups (75th and 99th quantile) was found significant at 1% and 95 % significant level respectively. The observed positive effect of household size goes with the significant effect of labor as production input established in technical efficiency analysis part of the paper. The ML estimate for technical efficiency effect of being model farmer was insignificant while the quantile regression estimate was significant for the highest efficiency group of farmers (99th quantile) at 95% significance level. A farmer is expected to be in the highest efficiency group if he/she is selected as a model farmer in the village and this expectation goes with the significant quantile regression estimate obtained for the 90th quantile. Bothe the ME and the quantile regression estimates have declared significant effect of the rust mitigation intervention which was under action in the study area during the data collection period with the aim of improving beneficiary's production efficiency. The Estimated intervention effect were significant across the four efficiency quantile groups at least at 95% significance level. The estimated MLE effect of distance from residence to plot on farmers efficiency level was insignificant while the quantile regression estimates for the most efficient group (99Th quantile) was found having significant negative effect. Farmers production efficiency effects of wheat growing experience and number of years the farmer was living in the area were insignificant for both ML and quantile regression estimates (Table 4). This might be due to farmers tendency to stick to their long-adapted practices than opting to shift to anew practice as they get old and old and hence declining technical efficiency. This finding is consistent with the findings of Tolesa *et al* (2014), Arega (2003) and Kaleb *et al* (2016).

Concussion

The objective of the study was to examine the extent of farm specific technical inefficiency in the use of agricultural resources, and to determine the socioeconomic factors which affects wheat production efficiency level in the three wheat producing districts of East Gojam zone of Amhara region. Consequently Cobb-Douglas Stochastic Frontier Model was fitted to estimate farm level technical efficiency and the associated efficiency score. The analysis of technical efficiency determents was conducted employing both ML and quantile regression techniques. The analysis has confirmed presence of strong wheat production inefficiency across the three study districts (Gozamen, Wonbrema and Debre Elias) under the current given production technology. The estimated mean farm level technical efficiency was 0.78. As this result entails on the average wheat farmers in the area are achieving only 78% of the potential maximum output from a given mix of production inputs. Fertilizer amount, land size, seed density and oxen days have demonstrated their significant positive effect on farmers technical efficiency with production elasticity of 0.46, 0.35, 0.14 and 0.12 respectively. Participation in Adoption of rust resistance wheat varieties was demonstrated being a major determinant of efficiency across all estimated efficiency levels while household size and being model farmer have expressed their significant positive effect on the efficiency level of best performing (75th and 99th efficiency quantiles) farmers. The policy implications of findings of the study are that technical efficiency in smallholder wheat production in the study area could be increased by 19% on average through better use of available resources (e.g. land, fertilizer, seed and oxen days), given the current state of technology. This means, local government or other concerned bodies in the developmental activities working with the view to boost production efficiency of the farmers in the study area should work on improving productivity of farmers by giving especial emphasis for significant factors of production along with important socioeconomic factors.

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