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Technical Efficiency of Smallholder Wheat Farmers in Ethiopia: A Panel Data Approach

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Abstract

This paper aims to estimate the technical efficiency measures of wheat-producing farmers in Ethiopia using the stochastic frontier panel model. Data from 3482 farm households collected in two rounds of panels (2011 and 2014) was used to estimate the Translog stochastic frontier production function and factors influencing technical efficiency with a one-step maximum likelihood estimator. The production frontier function involves land, seed, inorganic nitrogen, pesticide, oxen power, and labor. The model showed that more than 95% of the total variation in output was a result of factors within the control of the farmer. The result also indicated that land, seed, nitrogen, and pesticide had significant positive effects on wheat output. Most sustainable agricultural practices and plot characteristics included in the production frontier had positive effects on wheat production. The covariates such as gender and education of the household head, credit access, and livestock holding were important in reducing the inefficiency of the wheat producers. However, land size was found to increase the inefficiency of wheat producers. The mean technical efficiency of 2011 and 2014 was 65.3 and 65.4 which was not significant implying limited technological and institutional progress in the wheat sector between the study time. Results revealed that on average wheat output can be increased by 35 percent without additional inputs. Improved access to direct inputs and identified environmental and socioeconomic factors are important in attaining a higher frontier in wheat production in Ethiopia.

Keywords: efficiency, Ethiopia, frontier, inefficiency, panel, technical, translog

JEL Codes: C23, C67, D24, D51, Q12, Q16

Introduction

Food insecurity is one of the key concerns in Africa resulting from low agricultural productivity and rapid population growth. Per-capita food production in Africa has generally worsened over the last half-century compared to other regions in the world (Pretty et al., 2011). This can partly be attributed to inefficiencies in the production of major staple crops although there are variabilities across different regions (Mugera and Ojede, 2014). Wheat is one of the key staple food crops that provide about 20% of protein and calories worldwide (Bushuk, 1997). Its demand is projected to grow in the coming decades, especially in developing countries to feed the increasing population. Wheat is also considered to be one of the strategic food security crops in many parts of Africa (Ahmed et al., 2013).

Despite the importance of wheat for food security in Ethiopia, its productivity is low. For example, in 2022, the average national wheat yield in Ethiopia was only 3 ton ha^{-1} compared to what can be achieved from on-farm (5 t ha^{-1}) and on-station trials (5.5 t ha^{-1})[1] of agricultural research in the country (MoANR, 2016; CSA, 2021). Key factors accounting for the low productivity include soil fertility degradation and variable climate. The institutional capacity for technological innovation and diffusion at scale to overcome these challenges is lacking. In Ethiopia, smallholder farmers account for about 95% of the national agricultural output (CSA, 2021). Thus, options to increase production include improving smallholders' productivity through targeted policy innovations and expansion of farmland. Arable land is already a limiting production factor and thus increasing production through expansion of cultivation area (second approach) is not a feasible option. Currently, there is an exertion to increase grain wheat production through costly irrigation systems, for example in the Afar region. However, smallholder wheat farmers' output growth can be increased through two major strategies. The first strategy could be promoting new technological innovations and inputs that induce upward shifts in the production frontier. The second strategy could be expanding the diffusion of available best management and agronomic practices to increase farm productivity, enhance soil fertility and reduce the negative effects of climate variability (maintain the environment) and improve the technical efficiency of smallholder farms.

[1] See yield gap analysis of major staple crops (http://www.yieldgap.org/ethiopia).

While the first strategy requires long-term investments and considerable funds and efforts to yield long-run benefits, improving technical efficiency offers immediate benefits at a lower cost. In this context, technical efficiency is the ability to produce the maximum possible output from a given input set; else, a given level of output using the minimum proportions of scarce resources, is critical in determining the competitiveness and economic presentation of Ethiopian wheat producers. Productive efficiency is of particular importance in periods of climate change and financial strain when the viability of farm operations is being risked. Knowledge of the level and drivers of technical efficiency of smallholder wheat production that can help decision-makers in the pursuit of improved economic presentation is important and timely.

Studies on the technical efficiency of smallholder wheat farmers and their determinants in Ethiopia are scanty. These studies particularly use cross-sectional data, and specific geographical areas (Bekele et al., 2009; Yami et al., 2013; Wudineh and Endrias, 2016; Mamo et al., 2018). To our knowledge, no studies investigated the technical efficiency of wheat farmers at the household level in Ethiopia over time using a nationally representative panel data set, although maize technical efficiency panel data were used by Oumer et al. (2022) in Ethiopia, rice panel data in Bangladesh (Alam et al., 2011), and wheat panel data by Goyal (2003) in India. Above all, these prior studies fail to consider management practices such as cereal-legume rotation, crop residue retention, conservation tillage, and soil conservation structures. Management practices vary from farmer to farmer and even from plot to plot and thus may lead to a different production function for each farmer or plot. The advantages of panel data models over the cross-section include avoiding some problems of distributional assumptions, giving a large number of data points, separating individual and time-specific effects from the joint effect, and enabling to estimate of the inefficiency of time-invariant inefficiency (Greene, 2008).

Differently, this study is relatively inclusive because it considers management practices in the production function and covers major wheat growing areas, and uses relatively large representative samples. Therefore, an attempt has been made to investigate household-level specific technical efficiency for wheat production and its determinant factors, and the effects of management practices on technical efficiency in major wheat growing areas of Ethiopia.

Methodology

Study area and sampling

A multistage sampling procedure was used to select study *kebeles* from each district and farm households from each *kebele.* First, about 61 districts were selected based on wheat production potential from four regional states, namely, Oromia, Amhara, Tigray, and Southern Nations and Nationalities People Region (SNNPR) (Figure 1). Then, a proportionate random sampling procedure was used to select 3 to 6 *kebeles* in each district and 10 to 24 farm households in each *kebele*.

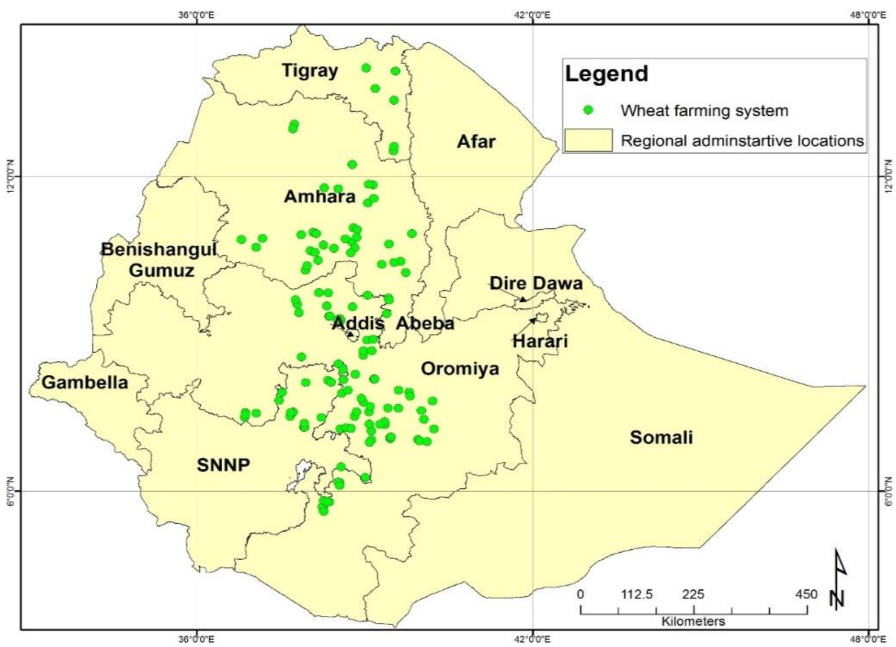

Figure 1: Map of the study *kebeles* representing the major wheat farming areas of Ethiopia

Empirical model

We adopt a heteroscedastic stochastic frontier analysis (SFA) approach to empirically investigate the effects of SAPs and other variables on the mean of the distribution of efficiency. This approach is justified because heterogeneity in output across farm households is abundant and can be attributed to differences in environmental variables that vary over time and space. We assume that all farm households face the same production technology, but there are differences in access and effective use by individual farmers due to environmental variables (Kumbhakar et al., 2014, Coelli et al., 1999). The environmental variables (sustainable intensification practices (SIP) and plot characteristics in our case) are not direct inputs and therefore are not included in the deterministic production frontier. Instead, they affect the performance of farm households in achieving optimal output and influence the degree of productive inefficiency. In this regard, environmental variables may influence the degree of technical inefficiency by shifting its mean. Thus, we used the approach to parametrize the mean of the pre-truncated inefficiency term as a linear function of environmental variables (Reifschneider and Stevenson, 1991, Kumbhakar et al., 1991, Huang and Liu, 1994, Battese and Coelli, 1995). The model can be specified as:

$lny_{it} = \alpha + lnf(x_{it};\beta) + \varepsilon_{it}$ ………………………….. (1)

$\varepsilon_{it} = v_{it-}u_{it}$

$v_{it} \sim N(0, \sigma_v^2)$

$u_{it} \sim N^{+}(u_{it}, \sigma_u^2)$

$\mu_{it} = \delta_0 + \delta'(z_{it}, s_{it}, m_{it})$

Where y_{it} is the log of output for farmer i at time $t;$ α is a common intercept; $f(x_{it};\beta)$ is the production technology; and x_{it} is the vector of inputs in logarithms; β is the associated vector of parameters to be estimated, and ε_{it} is the composed error of a two-sided symmetric random noise v_{it} and a non-negative one-sided inefficiency u_{it}. The inefficiency function u_{it} has a constant variance σ_v^2 and mean of μ_{it} which is a linear function of environmental variables z_{it}. SAPs s_{it} and socio-economic factors m_{it} and δ is a vector of parameters to be estimated.

Estimation procedure

The technical efficiency of the firm is defined as a ratio of the observed output to the maximum feasible output (where $U_{it} = 0$). Thus, the technical efficiency of farmer i at time t can be specified as follows:

$TE_{it} = \frac{y_{it}}{\exp f(\mathrm{X_{it}};\beta) * \exp(\mathrm{v_{it}})} = \exp(-\mathrm{u_{it}})$ …………………… (2)

Because $\mathrm{u_{it}}$ is a non-negative truncation of the normally distributed random variable, TE_{it} can lie between zero and unity, where unity indicates that this farmer is technically efficient. Otherwise TE_{it} <1 provides a measure of the shortfall of observed output from the maximum feasible output in an environment characterized by $\exp(-\mathrm{u_{it}})$ which allows for variations across producers.

A maximum likelihood (ML) approach is commonly employed for the estimation of a stochastic frontier, which rests on the assumption that the distribution of the errors is basically known. The ML estimation of the stochastic frontier model yields the estimate for beta (β), sigma squared (σ^2) and gamma (γ), and are variance parameters; γ measures the total variation of observed output from its frontier output. This study uses the parameterization following Battese and Coelli (1995) and given as, $\sigma^2 = \sigma_v^{\ 2} + \sigma_u^{\ 2}$ and $\gamma = \sigma^2{}_u / (\sigma_v^{\ 2} + \sigma_u^{\ 2})$, where the gamma lies between zero and one ($0 \le \gamma \le 1$). If the value of γ is very close to zero, then the deviations are due to noise, and/or if the value of γ is very close to 1, then the deviations are from inefficiency factors. The technical inefficiency model suggested by Battese and Coelli (1995) is presented as follows:

$u_{it} = Z_{it}\delta + \omega_{it}$ ……………………………………………… (3)

Where Z_{it} is a vector of exogenous variables; δ is a set of parameters to be estimated simultaneously with the frontier production function; ω_{it} is a random variable that is assumed to be distributed, $\omega_i \sim N(0, \sigma_\omega^2)$. The SFA as a parametric method requires assuming a specific functional form a priori, the frontier model is estimated using econometrics via some variant of the maximum likelihood method (Coelli et al., 2005).

Based on production economic theories and empirical evidence, efficiency variables were included in the econometric models (Battese and Broca, 1997; Kumbhakar et al., 2012; Oumer et al., 2022). In this study, we presume that wheat farmers employ the existing production technology to maximize output given a set of inputs in a diverse production environment. Thus, farmers with the same input packages may produce different output levels and vary in their technical efficiency levels too. The efficiency differences could be attributed to differences in household characteristics or human capital (age, education, gender, family size, experience), institutional variables (credit, extension, group membership, market access), management practices (conservation tillage, crop residue, and soil conservation), and plot characteristics (topography and fertility conditions).

Choice of functional forms

There are several functional forms of production to choose from in the case of SFA. These include Cobb-Douglas (CD), Constant Elasticity of Substitution (CES), Translog (TL), generalized Leontief (GL), normalized quadratic (NQ), and variants (Coelli et al., 2005). To estimate the number of alternative functional forms and select the best-fit form to the data at hand, it is recommended to perform a likelihood ratio test (Coelli, 1996). In production economics, Cobb-Douglas (restricted) and Translog (flexible) models are the two most common functional forms which have been used in the empirical frontier analysis (Oumer et al., 2022). Thus, the adequacy of one functional form (for example, CD) should be tested against another functional form (for example, TL). The CD and TL models can be specified as follows in equations 5 and 6, respectively.

$$lnY_{it} = \beta_0 + \sum_{i=1}^{k} \beta_i lnX_{it} + (v_{it-}v_{it}) \ldots\ldots (5)$$

$$lnY_{it} = \beta_0 + \sum_{i=1}^{k} \beta_i lnX_{it} + \frac{1}{2}\sum_{i=1}^{k}\sum_{j=1}^{k} \beta_j \,(lnX_{it})\left(lnX_{jt}\right) + (v_{it-}v_{it}) \ldots\ldots (6)$$

To select the best specification (Cobb-Douglas or Translog), a hypothesis test is conducted by using the generalized likelihood ratio (LR) test statistic:

$$LR(\lambda) = -2\{\ln[L(H_0)] - [\ln(H_1)]\} \ldots\ldots (7)$$

Where L (H0) and L (H1) are the values of the likelihood functions derived from restricted (null) and unrestricted (alternative) hypotheses. This test statistic is assumed to be asymptotically distributed as a mixture of the chi-square distribution with a degree of freedom equal to the number of restrictions involved (Taymaz and Saatci, 1997). The null hypotheses are rejected when the test statistic (λ) exceeds the critical value of Kodde and Palm (1986). If the computed value of the test is bigger than the critical value, the null hypothesis is rejected and the Translog frontier production function better represents the production technology of farmers.

Data and variables

The data for this study come from all wheat-growing areas of Ethiopia. Farm household data were collected in 2011 and 2014 by the Ethiopian Institute of Agricultural Research (EIAR) in collaboration with the International Maize and Wheat Improvement Centre (CIMMYT). The data were nationally representative of the wheat farming system. The data were a balanced panel of 3,482 farm household observations collected in 2010/2011 and 2013/2014 production seasons across 27 zones, 61 districts, and 128 *kebeles* in the country.

The data included detailed information about production activities, inputs, and output, socio-economic and policy variables as well as farm management practices. The farm household data were collected at the plot level. However, the data were aggregated at the household level for this specific paper. The definitions and descriptive statistics of the factors of production and various environmental variables hypothesized to influence technical efficiency are presented in Table 1. Overall, the major variables included in the analysis are grouped into four categories. These are conventional inputs, sustainable agricultural practices, plot characteristics, and, socio-economic factors. The variables are briefly described below.

Table 1: Variables used in the model, measurements, and its descriptive result

Model variables	Definition of the variables and measurement units	Measurement unit	Mean	SD
Dependent variable (y_{it})				
Output	Quantity of wheat grain a farm household produced	Kilogram	1211.72	1699.44
Direct inputs (x_{it})				
Land	Land area used for wheat production	Hectare	0.72	0.71
Seed	Quantity of wheat seed used	Kilogram	116.69	119.23
Oxen	Oxen drought power for plowing	Oxen-days	16.36	17.50
Labor	Quantity of labor used for production	Person days	44.41	37.71
Nitrogen[2]	Quantity of nitrogen nutrients used for production	Kilogram	20.06	24.23
Pesticide	Quantity of pesticide used for production	Liter or kg	0.36	0.55
Sustainable agricultural practice (s_{it}) and plot characteristics				
Improved variety	Adoption of improved wheat variety	1: Yes 0: Otherwise	0.62	0.49
Good fertility	Good soil fertility	1: Yes 0: Otherwise	0.37	0.48
Medium fertility	Medium soil fertility	1: Yes 0: Otherwise	0.52	0.49
Poor fertility	Poor soil fertility	1: Yes 0: Otherwise	0.11	0.31
Gentle slope	Gentle slope	1: Yes 0: Otherwise	0.61	0.49
Medium slope	Medium slope	1: Yes 0: Otherwise	0.34	0.47
Steep slope	Steep slope	1: Yes 0: Otherwise	0.05	0.22
Tillage frequency	Frequency of tillage during production season (lower frequency indicates reduced tillage)	Number	4.09	1.08
Manure	Households used manure on wheat land	1: Yes 0: Otherwise	0.27	0.45
SWC	Households constructed soil and water conservation structures on wheat land	1: Yes 0: Otherwise	0.40	0.49
Residue retention	Households retained the previous year's crop residue on the land	1: Yes 0: Otherwise	0.21	0.41
Phosphate	Phosphate applied	Kilograms	22.55	21.84
Socio-economic factors (m_{it})				
Gender	Gender of the household head	1: Male 0: Otherwise	0.93	0.26
Age	Age of the household head	Years	44.60	12.62
Education	Education level of the household head	Years	2.99	3.32
AE	Adult equivalence (active labor force)	Number	5.63	2.03
Farm experience	Wheat farming experience of the household head	Years	17.63	11.02

[2] 46% from UREA and 18% from DAP

Credit	Household head has access to credit services	1: Yes 0: Otherwise	0.14	0.34
Cooperative	Membership of the household head in coops	1: Yes 0: Otherwise	0.26	0.44
Extension contact	Number of extension contact in the production year	Number	6.14	7.40
Total land	Total land area of the household	Hectares	1.95	1.59
Distance to the nearest market	Distance to the main market from household residence	Kilometers	8.78	6.06
Livestock	Index of livestock ownership of the household	TLU	6.89	5.55

Source: Own computation

Conventional (direct) inputs used in production

The conventional inputs used were land, oxen draught power, seed, labor, inorganic nitrogen, and pesticide. The quantity of wheat seed used by farmers was measured in kilograms and the average seed used was 116.69 kg. The average farm for wheat used in the sample was 0.72 hectares. Labor data is measured in person days. On average a farmer allocates 44.41 man days for wheat production on their land. Inorganic nitrogen is measured in kilograms. Farmers use both DAP and UREA fertilizers for wheat. The quantity of nitrogen used by the household for the production of wheat was extracted based on the proportion of nitrogen in both fertilizers. On average farmers used 20.6 kg of nitrogen for wheat production. Oxen power is used for plowing in Ethiopia and is measured in oxen days. On average, 16 oxen days were used to cultivate wheat on an average area of 0.72 hectares of land. Data on herbicides, insecticides, and fungicides were added as they have the same unit of measurement. The average quality of pesticide used by wheat-producing households was 0.36 kilograms or liters.

Sustainable agricultural practices and plot characteristics

Sustainable agricultural practices (SAPs) can be used alongside conventional inputs. Their adoption can enhance wheat production efficiency and offset the adverse effects of soil degradation and climate variability. We consider five SAPs based on their agronomic merits and natural resource management benefits. These SAPs include the use of improved wheat varieties, the use of animal manure, soil, and water conservation (SWC) measures (bunds, terraces, grass strips, and box ridges), minimum tillage, and residue retention. The data showed that 62% of farmers adopted improved wheat varieties. The average tillage frequency which is a proxy for minimum tillage was 4. The use of manure, SWC structures, and residue retention was 27%, 40%, and 21%, respectively among wheat-growing households. We also control for biophysical differences due to agroecological conditions such as topography and soil quality. Soil fertility is classified into poor, medium, and fertile as perceived by farmers. The data shows that the majority of sampled farmers' wheat plots had medium soil fertility (52%) and gentle sloped (61%) plots. Furthermore, 27%, 40%, and 21% of the sampled households used manure, practiced SWC measures, and retained crop residues on their wheat plots (Table 1).

Socioeconomic factors

Socioeconomic and institutional variables can influence the process by which inputs are converted into output. Differences among farm households regarding production resources, level of education, access to institutions, access to information, and credit are also expected to influence production performance. Accordingly, we considered gender, education, farm experience, active labor force, access to credit, market and access extension services as well as economic variables such as land and livestock on the inefficiency model of stochastic production frontier.

Results and Discussion

Results from the hypothesis test

Before rushing into the estimation, we made a test to choose between Cobb-Douglas (CD) and Translog (TL) using the LLR test. The LL functional values of both CD and TL production functions were -3183.1 and -3092.7, respectively. The LR value computed therefore was 180.72 and this value is greater than the upper 1% critical value of the $\chi 2$ at 21 degrees of freedom (52.88). This shows that the coefficients of the interaction terms and the square specifications of the input variables under the Translog specifications were not different from zero. As a result, the null hypothesis (restricted or CD) was rejected and the Translog functional form best fits the data (Table 2).

Table 2: Hypothesis testing on the Stochastic Frontier Functional form

Null hypothesis	Test statistics	Critical value	Decision
$\boldsymbol{H_0 = \psi = 0}$	**180.72**	**38.30**	**Reject**

Note: All critical values are at a 1% level of significance and the critical values are obtained from Table Kodde and Palm (1986) at 21 degrees of freedom.

Stochastic frontier analysis

The value of 0.953 of the gamma (γ) for the production function suggests that technical inefficiency had a significant effect on output. This means that 95.3% of the total variation in output was as a result of factors within the control of the farmer and that variation in wheat production could be attributed to inefficiency. The remaining 4.7% was due to factors outside the control of the farmers (Table 3). The value of gamma reveals the fact that most farmers in the study area are using their existing resources inefficiently.

Output elasticities

The result revealed that conventional (direct) inputs, except labor (measured in man-days) and oxen draught power (oxen days), have positive and statistically significant effects on wheat output. Wheat output is most responsive to land and seed inputs relative to nitrogen fertilizer, and pesticide use. The estimates of the second-order terms in the frontier function are also spontaneous. The coefficients are statistically significant for nitrogen and pesticide. These results imply that farmers are operating at increasing returns to the use of nitrogen and pesticide. The interaction effect of seed and nitrogen is negative and significant. The result implies that the influence of nitrogen on wheat yield decreases as the amount of seed applied increases or vice versa. The same is true for land and labor interaction. Overall, the sum of the elasticities is 1.116 implying that they are operating at increasing return to scale, and hence using more inputs proportionally would lead to proportionate wheat output increments under the current state of technology (Table 3).

Table 3: Parameter estimates of the stochastic frontier analysis

Variables	Coefficient	SE	P>z
Direct (conventional) inputs			
Land	0.470 ***	0.045	0.000
Seed	0.421 ***	0.038	0.000
Nitrogen	0.124 ***	0.020	0.000
Pesticide	0.101 ***	0.018	0.000
Oxen	0.001	0.032	0.966
Labor	-0.001	0.026	0.979
0.5 $Land^2$	0.141	0.113	0.213
0.5 $Seed^2$	0.060	0.088	0.495
0.5 $Nitrogen^2$	0.080 ***	0.009	0.000
0.5 $Pesticide^2$	0.039 ***	0.009	0.000
0.5 $Oxen^2$	0.075	0.067	0.268
0.5 $Labour^2$	0.018	0.030	0.544
Seed x Land	0.088	0.071	0.213
Seed x Pesticide	0.018	0.012	0.137
Seed x Oxen	-0.048	0.053	0.363
Seed x Labor	-0.001	0.063	0.983
Seed x Nitrogen	-0.038 ***	0.013	0.005
Land x Pesticide	-0.007	0.015	0.648
Land x Oxen	0.023	0.056	0.685
Land x Labor	-0.209 ***	0.068	0.002
Land x Nitrogen	0.023	0.017	0.162
Pesticide x Oxen	0.001	0.012	0.961
Pesticide x Labor	-0.006	0.012	0.611
Pesticide x Nitrogen	-0.000	0.003	0.930
Oxen x Labor	-0.005	0.054	0.924
Oxen x Nitrogen	-0.003	0.014	0.827
Labor x Nitrogen	-0.015	0.014	0.302
Constant	-0.627 ***	0.099	0.000
Environmental variables and shifters			
Good soil fertility	0.184 ***	0.033	0.000
Medium soil fertility	0.085 ***	0.031	0.006
Gentle land slope	0.144 ***	0.040	0.000
Medium slope	0.055	0.040	0.170
Improved variety	0.134 ***	0.022	0.000
Plowing frequency	0.048 ***	0.011	0.000
SWC	0.005	0.020	0.800
Manure	0.007 *	0.004	0.060
Crop residue	0.023	0.023	0.310
Phosphate	0.098 ***	0.020	0.000
Year	0.007	0.017	0.691
Inefficiency effects component of the frontier model			
Gender	-1.223 **	0.538	0.023

Education	-0.161	***	0.059	0.006
Adult equivalence	-0.058		0.083	0.479
Credit	-0.816	*	0.456	0.073
Number of extension contacts	-0.386		0.273	0.158
Total land owned	0.304	**	0.137	0.026
Livestock	-0.222	**	0.088	0.011
Farming experience	-0.014		0.013	0.282
Distance to the nearest market	-0.054	**	0.027	0.049
Variance parameters				
Variance of technical inefficiency [Sigma u]	1.577	***	0.244	0.000
Variance of random error [Sigma v]	0.350	***	0.014	0.000
Variance ratio parameter (Lambda (λ))	4.509	***	0.243	0.000
Gamma (γ)	0.953	***		0.000
Wald chi^2 (36)	6844.78	***		0.000
Number of observations	3482			

Note: *, **, *** Significant at 10, 5, and 1% significance level

Effects of sustainable agriculture practices and plot characteristics on the production frontier

The result from the econometric model revealed that plot characteristics and soil quality have a significant effect on the mean technical efficiency. Wheat output is significantly responsive to good and medium soil fertility as compared to poor soil fertility. Poor soil fertility derives the farmers to use more labor, nitrogen, and oxen power input to increase production so reducing technical efficiency. Latruffe et al. (2004) also found a positive effect of soil quality on grain crop technical efficiency.

In regards to plot slope, the wheat output is positively and significantly responsive to gentle land slopes than steep slopes. Steep plots require more time in plowing and are usually subject to water erosion and are likely to be of lower productivity. The result is in line with Ahmed et al (2002) who found the negative effect of land slope on crop yields. The result also shows that the coefficients of improved wheat variety and manure application are positive and statistically significant. These suggest that the intensive use of these technologies and practices enhance the wheat output produced. The positive relation between TE and the use of improved variety was also consistent with Toiba et al. (2021) and Oumer et al. (2022). Wheat output has a positive and significant response to plowing frequency implying that conservation tillage is not appropriate for wheat production. The positive elasticity of the number of plowing indicates that as the number of plowing increased for land preparation its effect on wheat yield is positive and significant. Other studies also found similar results.

Fatima and Khan (2015) and Ali and Khan (2014) found that plow hours would increase production.

Inefficiency factors

Many of the socio-economic variables are found to have statistically significant positive effects on technical efficiency. Male-headed households are found to be more efficient, possibly a reflection of the gender disparity that leads to greater resource constraints in female-headed farm households. The result is consistent with the findings of Abdulai et al., (2013), Yiadom-Boakye et al., (2013), Zheng et al., (2021), Pangapanga-Phiri and Mungatana (2021), and Gbigbi (2021) who found that male-headed households are technically more efficient than their female-headed households. Education of the head, credit access, number of livestock owned, and market access positively influenced the technical efficiency level.

The positive effect of education on technical efficiency is in line with the results of Shahbaz et al. (2021), Khan et al. (2022), and Wu et al. (2022). Education enhances the use of product information, market information, and record keeping.

The negative coefficient of credit on inefficiency or the positive effect on efficiency was also observed. Credit access increases farmers' efficiency because it temporarily solves the shortage of liquidity/working capital. The result corroborates with Dessale (2019), Missiame et al. (2021), Birhanu et al. (2021), Pangapanga-Phiri and Mungatana (2021), and Abate et al. (2022). Farmers' market access has a positive effect on the efficiency of wheat production. Market access enhance the farmers to decide what to produce for the market. The result is in line with Tesfaw et al. (2021) and Asfaw (2021).

Livestock ownership which is the proxy for wealth of the rural households is positively related to technical efficiency. Ownership of livestock is important for farmers to get cash for the purchase of direct inputs such as fertilizer and seed. This culture is common in the rural part of the country where farmers sell their livestock and purchase production inputs. Debebe et al. (2015) and Koye et al (2022) also found a negative relationship between livestock ownership and technical inefficiency.

On the other hand, total land owned reduce the technical efficiency of wheat farms implying resource share to other farms. Smallholder farmers who are characterized by resource constraints for input and technology may allocate their limited money to every farm plot using the recommended rate of inputs. In the Ethiopian case, land is on the hand of old farmers and youth are migrated to towns and cities. This has derived old farmers to be inefficient in wheat production. Bozoğlu and Ceyhan (2007) also found a positive relationship between total land size and inefficiency.

Technical efficiency scores

The average technical efficiency score for the model (Battese and Coelli, 1995) is 65.4% with a standard deviation of 18.6% using Battese and Coelli, 1995 (bc) command and 63.6% with a standard deviation of 18.9% using jlms (Jondrow, Lovell, Materov, and Schmidt, 1982.) command (Table 4). This value indicates the possibility of increasing output by 35% or 36% for bc and jlms, respectively given the existing level of inputs. Several authors also found different technical efficiency scores using cross-sectional data. Gelaw and Bezabih (2004), Wassie (2012), Mamo et al. (2018), and Hailu (2020) estimated the TE score was 71.9%, 79.9%, 76.9%, and 62%, respectively. Our result indicated the mean TE of 2014 is almost equal to 2011 which shows limited technological development and institutional progress for wheat production during the periods. The study does not observe a significant difference between the two years' efficiency scores using both estimation approaches.

Table 4: Efficiency score using different estimation methods

Methods	2011		2014		Overall		P-value
	Mean	SD	Mean	SD	Mean	SD	
BC	0.653	0.187	0.654	0.186	0.654	0.186	0.913
JLMS	0.636	0.189	0.637	0.188	0.636	0.189	0.923

The kernel density distributions and efficiency score from the model is presented in Figure 2 and 3. Figure (2) shows the kernel density distribution of the technical efficiency of wheat farmers. The result depicted that the majority of wheat farmers' efficiency score is above 60%. The study further classified the efficiency score to estimate the proportion of farmers under each category. Accordingly, as shown in figure (3), the estimate presented that 66 and 69% of farmers are between an efficiency score of 61-90% based on jlms and bc estimation methods, respectively.

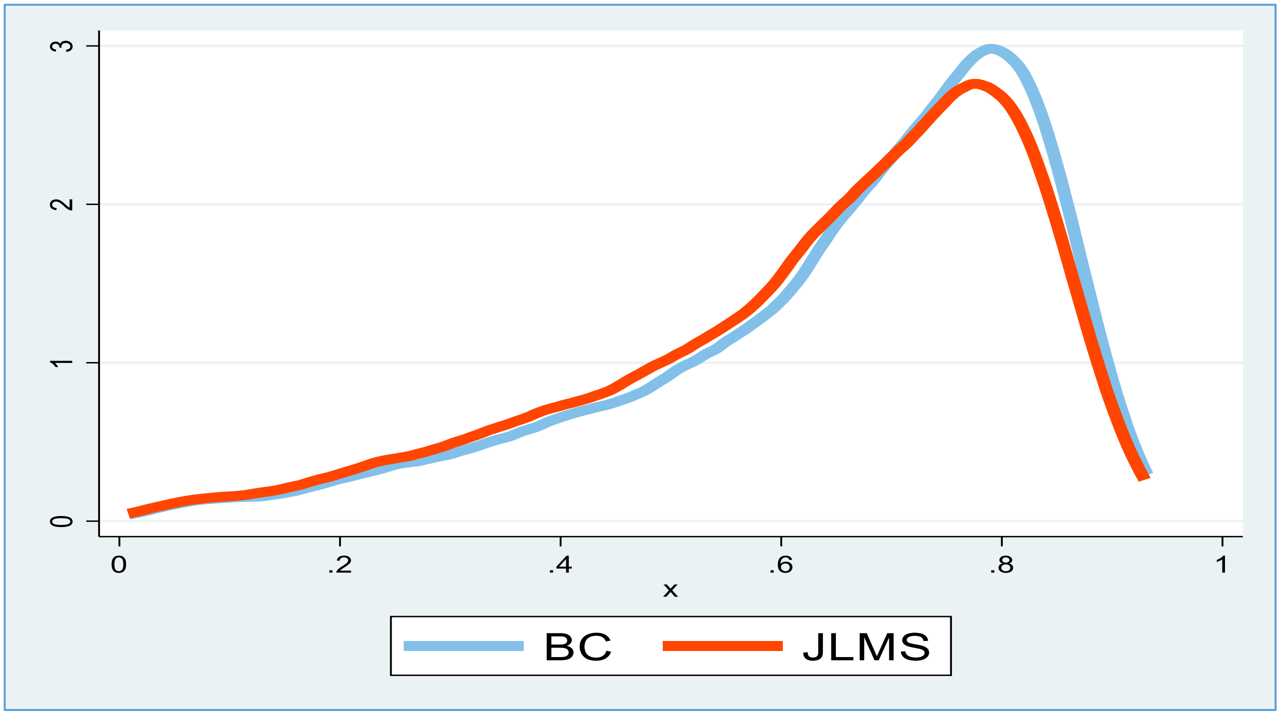

Figure 2: Kernel density estimates of technical efficiency under alternative estimation methods

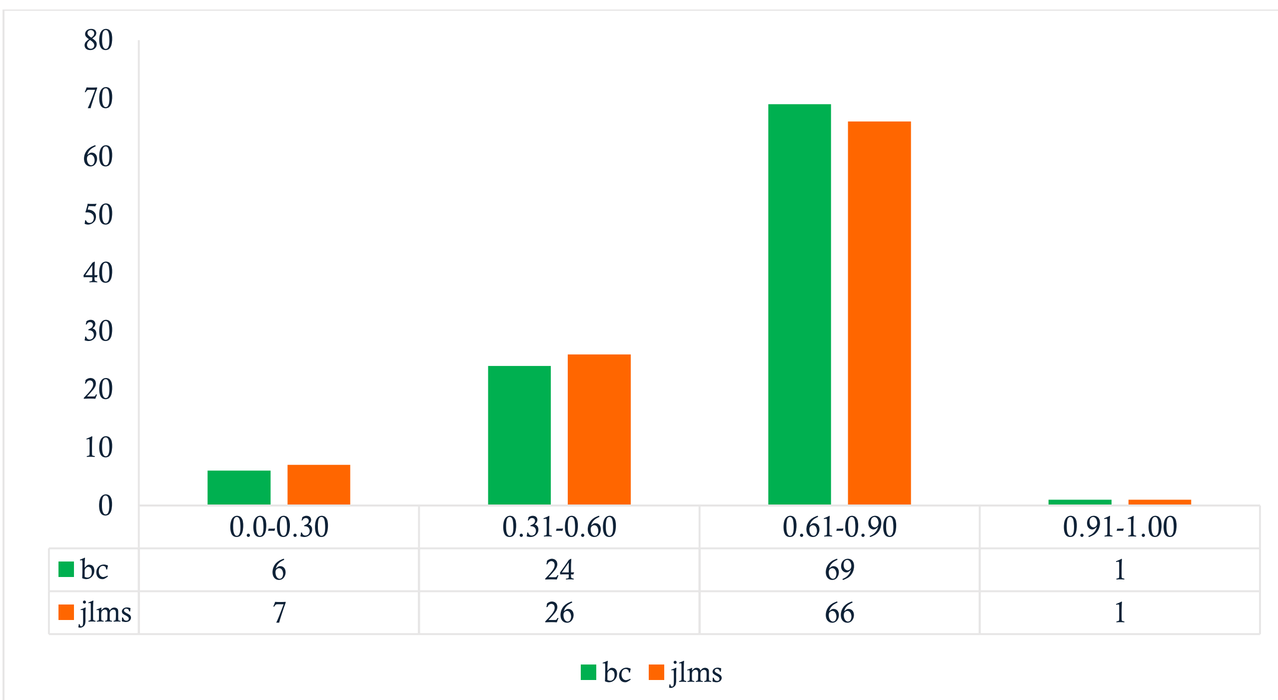

Figure 3: Wheat farmers' efficiency score under alternative estimation methods

Conclusions and Recommendations

The paper used the stochastic frontier production function with a time-varying model to examine the changes in technical efficiency at the farm level for wheat farmers using balanced two-time panel data (2011 and 2014 data). The model showed that more than 95% of the total variation in output was a result of factors within the control of the farmer. The mean technical efficiency has not shown a significant difference between the two panels (2011 & 2014). The mean technical efficiency (TE) of wheat farmers is 64.5%. The wide variation in technical efficiency is an indication that most of the farmers are still using their resources inefficiently in the production process and there still exists opportunities for increasing wheat production by improving their current level of technical efficiency. Hence, wheat production in the study area can be increased by 35.5% at the existing level of inputs and current technology or without any additional resources by operating at a full technical efficient level.

The econometric estimate indicated that wheat land size, seed, nitrogen fertilizer, pesticide use, use of improved wheat varieties, plowing frequency, and land quality were found to explain the frontier function. Various socio-economic and institutional factors are responsible for the observed inefficiency and further rise in inefficiency in wheat production based on the result. Accordingly, education of the household head, gender, credit access, number of livestock, and market access affect the inefficiency of wheat farmers negatively and significantly meaning affects the efficiency positively. The total land size of the farmers affects the inefficiency positively and significantly. Based on the results, the following recommendations are drawn.

- The result revealed that wheat farmers are not fully efficient in Ethiopia and that the level of technical efficiency reducing overtime at the farm level is not adequate to cope with the current wheat demand due to population growth and modernization. This indicates the need to consider ways to improve the efficiency and reduce the inefficiency of wheat farmers.
- The positive elasticities of nitrogen, seed, and pesticide indicate that output increases as these inputs. This suggests government and other development partners act accordingly in the way these inputs are supplied sufficiently and timely to farmers. In this way, policymakers should make further efforts in strengthening financial

institutions like microfinance and other arrangements that can relax farmers' liquidity constraints and help them to afford these inputs.

- The result indicates that land fertility is found to have a positive and significant effect on efficiency. Thus, improving and maintaining the fertility status of land by applying improved land management practices would increase the efficiency of farmers there by wheat production.
- The use of improved wheat varieties has significantly increased the technical efficiency of wheat farmers. Concomitantly, the technical efficiency of wheat farmers has not shown progress over time may be due to stagnant technological progress in the sector. Hence, research, extension, and other development partners are responsible to generate, popularize and disseminate the improved variety of wheat to boost the technical efficiency of wheat and thereby wheat yield.
- The result also indicated that male-headed households are more efficient than female-headed households. The likely policy to deal with bridging the gap between male and female-headed household yield may be through improving the economic status of women. This could capacitate the women farmers to use the optimum conventional inputs (improved seed, nitrogen, and pesticides) per unit of land.
- The positive and significant coefficient of plowing frequency suggests the importance of traditional inputs in subsistence agriculture. However, the practice should be done and intensified in consultation with experts and development agents as over-plowing aggravate soil erosion and causes disturbance.
- The positive and significant coefficient of manure use on the technical efficiency of wheat also implies the importance of sustainable agricultural practices in increasing wheat production.
- Credit access has negatively and significantly contributed to the inefficiency or positively to the efficiency of wheat farmers. The positive influence of credit access on technical efficiency provides a basis for the provision and use of credit. The high initial capital consumption and running costs of wheat farming can be supplemented through credit where farmers are unable to raise the required funds for seed, fertilizer, and pesticides. Therefore, credit access should be enhanced to increase use for those farmers who are unable to raise the cost involved in wheat production.

- Market access is negatively related to inefficiency or positively to the efficiency of wheat farmers. Policies should, therefore, target improving transport and market infrastructure in all areas to improve efficiency. This will not only improve market access for output but also for inputs.

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