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Production efficiency of wheat farmers in the Arsi Zone, Oromia Region of Ethiopia

Zenaye Degefu Agazhi[1] · Melkamu Mada[1] · Mebratu Alemu[1]

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Abstract
Wheat is a cereal crop that contributes to food security; thus, Ethiopia must boost the production efficiency of wheat to meet the sustainable development goal of eradicating hunger and poverty. Consequently, a significant revolution is occurring in the Ethiopian wheat industry to improve production and productivity. Therefore, it is critical to understand the current level of wheat farmers' efficiency, as its production is highly influenced by existing agricultural technologies and climate change, which makes it dynamic. Accordingly, this study employed the parametric Cobb–Douglas stochastic frontier and two-limit Tobit models to evaluate wheat farmers' efficiency and determine their drivers in Ethiopia's largest wheat-producing area, the Arsi Zone. A multistage sampling strategy was applied to obtain a representative sample of 422 wheat farmers. The model's output suggested that the average technical, allocative, and economic efficiency scores were 80.8%, 88.1%, and 71.3%, respectively. It is confirmed that wheat farmers' efficiencies can increase with household head age, education level, livestock ownership, contact with extension agents, wheat mechanization, and involvement in non/off-farm activities but decrease with household distance from the main market and total land holdings. To realize the potential gains from wheat cultivation in Ethiopia, the government needs to develop policies and strategies that enhance farmers' education, livestock production, and extension contact, facilitate infrastructure, market development, and wheat mechanization, and promote non/off-farm activities.

Keywords Wheat · Efficiency · Stochastic frontier model · Cobb–Douglas · Two-limit Tobit · Ethiopia

1 Introduction

Agriculture remains the foundation of the Ethiopian economy which makes up more than 32.5% of the country's GDP in 2020–2021 [1] and employs nearly 77.2% of the population, even though it is giving way to the industry and manufacturing sectors. A total of 65.1% of Ethiopian agricultural GDP is derived from crop production [1], and cereal crops are the main source of caloric food for people's daily food consumption [2]. However, this sector in Ethiopia is highly subsistence due to its reliance on rain, low marketing facilities, poor infrastructural development, insufficient farm input, and climate change-induced natural disasters [3, 4]. Wheat is classified as a cereal crop, so its production contributes significantly to the country's economic development [5]. Ethiopia has enormous wheat production potential, which makes it the world's 18th and Africa's 2nd largest wheat producer. It accounts for approximately 15.31% of the Ethiopian total grain farmland (1.87 million hectares) and 17.71% of the total grain production (58.08 million quintals) [6] in the

✉ Zenaye Degefu Agazhi, zizusgs.agroeco@gmail.com; Melkamu Mada, melkamumada2002@gmail.com; Mebratu Alemu, mebselu1975@gmail.com | [1]Department of Economics, College of Business and Economics, Arba Minch University, Arba Minch, Ethiopia.

2021/2022 main production season. The demand for wheat in Ethiopia is rapidly expanding due to population growth and urbanization, which have shifted dietary preferences toward wheat-based convenience foods [7].

For a country such as Ethiopia to ensure food security and meet the nutritional needs of its rapidly expanding population, increasing wheat production efficiency is essential. In light of this, Ethiopia's wheat sector is currently undergoing a massive revolution, intended to swiftly expand wheat output, significantly close the supply–demand imbalance, and achieve wheat self-sufficiency as a national goal [8]. However, Ethiopia's wheat productivity in 2022–2023 was 3 tons/ha, which is below both the global average (3.55 tons/ha) and that of Egypt (6.4 tons/ha) [9] due to biotic and abiotic constraints and technical, socioeconomic, and institutional factors. This research was undertaken in the Arsi zone, Ethiopia's largest wheat producer. Wheat production in the Arsi zone accounts for 11.03% of the total wheat land (approximately 0.209 million hectares) and 12.45% of the total wheat production (approximately 7.2 million quintals) of the country [6].

Ethiopian wheat production is predominantly carried out by subsistence farmers, which results in low productivity and inefficient wheat production [5, 10, 11], mostly associated with problems of inadequate supply and high costs of critical farm inputs [8, 12]. It is critical to improve Ethiopia's wheat production efficiency to address the issues caused by an expanding population, climate change, and shifting demands. Understanding the current level of wheat production efficiency will result in better resource management and optimization that eventually increases the productivity and profitability of wheat production, which contributes to overall agricultural development and helps to achieve the national objective of ending hunger and poverty.

Numerous studies on the production efficiency of wheat in Ethiopia confirm the existing wheat production inefficiency, even though there is an opportunity to boost output from the current level of input and production technologies. However, the majority of these studies [11, 13, 14] focused on estimating technical efficiency, with only a few looking at all efficiency estimates simultaneously. Furthermore, Ethiopian wheat production is undergoing a tremendous revolution [8], and wheat production is dynamic similar to that in other agricultural sectors, and fluctuates with existing production technology and climate unpredictability. Therefore, recurrent studies on the production efficiency of wheat are needed. Accordingly, this study was undertaken in the Arsi zone of the Oromia regional state of Ethiopia to assess wheat farmers' technical efficiency (TE), allocative efficiency (AE), and economic efficiency (EE) and to identify their drivers.

2 Research methodologies

2.1 Description of the study area

The Arsi zone is located in the Oromia region of Ethiopia in the southeastern part of the country. It has a total area of 19,825.22 km^2 and is divided into 26 districts [6]. According to the Arsi Zone Office of Agriculture (2024), the rainy season begins in June and peaks in July and August, while the *Belg* season runs from February to April. The zone receives a yearly average rainfall of 1020 mm and a temperature that ranges between 20 and 25 °C. The zone has an altitude that ranges from 500 to 4377 m above sea level (m.a.s.l.) with four agroecological zones, namely, extreme highlands (above 3200 m.a.s.l.), the highlands (2300–3200 m.a.s.l.), midlands (1500–2300 m.a.s.l.), and the lowlands (below 1500 m.a.s.l.), which cover 6%, 34%, 40%, and 20%, respectively.

The population was officially estimated to be 3,980,967 people in mid-2022, with 49.92% males and 50.07% females [15]. The total population is composed of 88.14% rural residents, 11.59% urban residents, and 0.27% pastoralists. Wheat, barley, maize, tef, sorghum, and coffee are among the most important crops grown in the region. Wheat is the most important crop grown by 360,697 holders, accounting for 43.7% of the zone's total cereal production from its 39.8% zonally cultivated lands. The study sites are the Digeluna–Tijo, Dodota, and Ludehetosa districts, which are indicated in Fig. 1 below.

2.2 Data source and sampling techniques

This study was based on cross-sectional data collected by using a semi structured questionnaire and interviews with farm households that were selected randomly using a multistage sampling technique. In the 1st stage, the Arsi zone was purposively selected due to its wheat production potential. In the second stage, accessible major wheat-producing districts in the zone were identified for each agroecological zone with the help of key informants who knew the study

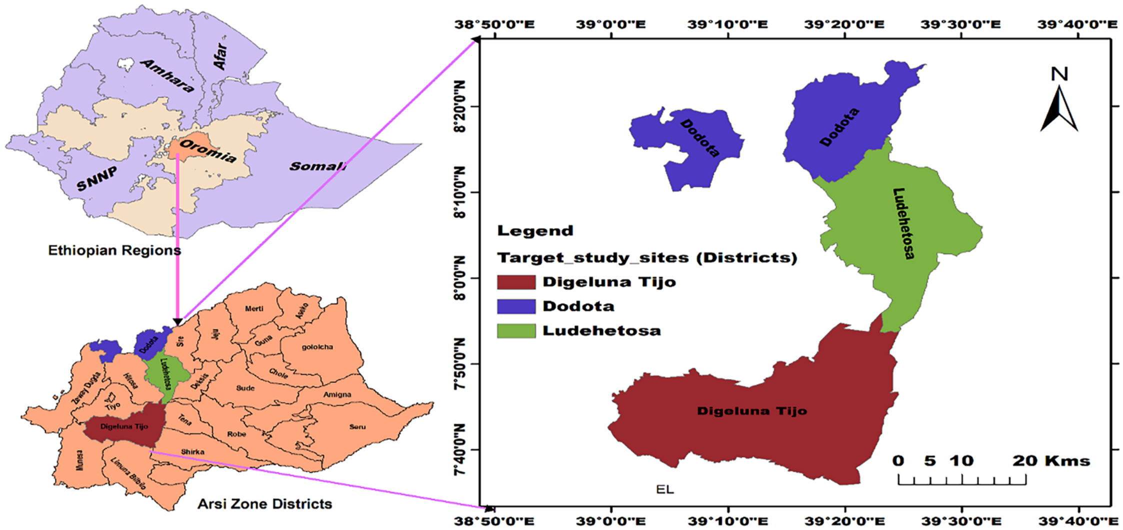

Fig. 1 Map of the study area

Table 1 Distribution of respondents among sampled districts and kebeles

Districts	Selected kebeles	Wheat producer households	Proportion	Sample house-holds
Dodota (Lowland)		11,827	29.1	123
	Tedecha Guracha	812	47.43	58
	Dodota Alaa	900	52.57	65
Digeluna Tijo (Highland)		17,118	42.1	178
	Gusha Temele	936	38.19	68
	Asabeka Welkite	835	34.07	61
	Chefa Guggessa	680	27.74	49
Ludehetosa (Midland)		11,727	28.8	121
	Adamare	862	43.85	53
	Gerda Busa	354	18.01	22
	Melka Jebi	750	38.15	46
Total				422

area well. Then, the highland districts of Digeluna–Tijo, the lowland district of Dodota, and the midland district of Ludehetosa were chosen randomly by the lottery method. In the 3rd stage, the total number of *kebeles*[1] in each district that corresponded to the district's agroecological class was listed. Then, based on the proportion of kebeles in each district, three kebeles from Ludehetosa, three from Digeluna-Tijo, and two from Dodota were randomly selected. Then, from the kebele-level administrative office, a list of households that produced wheat during the main agricultural production season of 2022/2023 was obtained. Finally, a total of 422 wheat producers were selected and distributed for each district (Table 1) based on the proportion of their total wheat producers using a simple random sampling technique.

2.3 Method of data analysis

2.3.1 Estimation of wheat farmer efficiencies

The two methods employed to evaluate smallholder farm efficiency levels are the parametric stochastic frontier model (SFM) and nonparametric data envelope analysis (DEA). The parametric SFM is based on an econometric

[1] Kebele is the lowest administrative unit in Ethiopia.

approach with a specific functional form, while the nonparametric DEA relies on mathematical techniques [16]. To estimate efficiency, both techniques use distinct approaches that consider random noise and flexibility in the structure of the production technology. SFM typically has only one output, whereas DEA can include multiple outputs from a producer [17].

Due to their intrinsic differences, the parametric SFM and nonparametric DEA approaches have been debated. Studies on measuring efficiency indicate that researchers can use either approach because there is little difference in the estimated results [18, 19]. According to [20], the SFM forecasts firm-specific inefficiencies and random errors that cause deviations from the frontier. Parametric SFM is still a commonly used approach for measuring farmers' production efficiency, despite its limitations in explicitly assuming a functional form for production technology and inefficiency term distribution. Since the SFM accounts for stochastic noise and enables hypothesis testing about production technology structure, the existing level of inefficiency, and overall model performance, it is regarded as a more accurate method for measuring efficiency. The objective of the study, data type, and functional forms used to represent the technology of production determine the model used in efficiency analysis. When there is a significant level of disturbance in the data due to measurement error, SFM is better than DEA for calculating the total factor productivity growth rate [16].

In this study, the SFM, which captures statistical noise that the decision-making unit cannot control, such as errors in measurement and changes in the environment, was used to estimate the coefficients of the production/cost function and the levels of wheat farmers' efficiencies (TE, AE, and EE) [20]. The functional forms that are most frequently utilized in SFM are translog and Cobb–Douglas (CD). To select the best-fit functional form for the data at hand, null hypotheses were tested using the generalized likelihood ratio (GLR), and CD was selected, as discussed in Sect. 3.2, which assumes unitary substitution elasticity, continuous production elasticity, and constant factor demand [20]. Using the CD over translog production function for smallholder farmers is endorsed, as the changes in returns to scale are unlikely to have a significant impact on production technology [21].

Accordingly, the CD-Stochastic Frontier Production Function (CD-SFPF) is specified as:

$$lny_i = \beta_0 + \sum_{j=1}^{6} \beta_i lnX_{ij} + v_i + u_i \tag{1}$$

where *ln* represents the natural logarithm, y_i is the wheat yield in quintals; X_1 is the land under wheat (hectares); X_2 is the labor (family/hired) (man/day); X_3 is the chemical fertilizer (kg); X_4 represents the seed (kg); X_5 is the oxen power (oxen-day); X_6 is the chemical (pesticide and herbicide) (liters); β_0 is the intercept; β_i are the coefficients of the production function; and v_i is a random error that is assumed to be independently and identically distributed N $(0, \sigma^2)$. u_i is an error term that is a one-sided nonnegative variable that indicates the household's technical inefficiency, which reflects how far the observed output falls below the potential yield from a given level of technology and inputs.

By assuming that the production function in Eq. (1) is self-dual CD, the respective cost function of the CD production function can be stated as:

$$lnTC_i = \alpha_0 + \alpha_1 lnP_{land} + \alpha_2 lnP_{labor} + \alpha_3 lnP_{seed} + \alpha_4 lnP_{fertilizer} + \alpha_5 lnP_{chemical} + \alpha_6 lnP_{oxen} + \alpha_7 lnY^* + (v_i + u_i) \tag{2}$$

where TC_i is the minimum cost of wheat production for the *i*th household; Y_i^* is the respective wheat yield adjusted for noise; P represents the prices of inputs; and α_s are their coefficients. Then, the input price and adjusted level of the output were substituted by using Shephard's Lemma technique into the subsequent input demand equations, and the economically efficient input vector of the *i*th farmer, X_{ie}, can be expressed as

$$\frac{\partial lnTC_i}{\partial P_n} = X_{ie}(P_i, Y_i^*, \alpha) \tag{3}$$

where n = 6 indicates the number of inputs used for wheat production.

The explained cost measure enables us to determine the level of AE and then EE, which can explain the technical efficiency of each wheat farmer in terms of observed output (Y_i) and the corresponding frontier output (Y_i^*) using the existing production technology [22].

Table 2 Hypothesized variables with expected effects on wheat production efficiency. Source: Own summary from empirical studies

Variables	Measurement	Expected sign	Related empirical studies
Age	Years	+	[10, 13, 31]
Education level	Years of schooling	+	[10, 13, 14, 31]
Livestock holding	TLU	+	[11, 25]
Distance from the main market	km	–	[10, 32]
Extension contact	Number of days per year	+	[10, 11]
Total farm size	Hectares (ha)	–	[13, 25]
Family size	Adult equivalent	+	[11]
Mechanization (plowing/harvesting)	Dummy (1 = yes)	+	[33, 34]
Credit utilization	Dummy (1 = yes)	+	[14, 31]
Participation in off/nonfarm activity	Dummy (1 = yes)	+	[10, 25]

$$TE_i = \frac{P'X_{it}}{P'X_i} = \frac{Y_i}{Y^*} \tag{4}$$

Then, the economic efficiency of each farmer is defined as the ratio of the minimum observed total production cost (TC*) to the actual total production cost (TC).

$$EE_i = \frac{P'X_{ie}}{P'X_i} = \frac{TC^*}{TC} \tag{5}$$

Following [23], the AE index can be derived from Eqs. (4) and (5) as indicated below:

$$AE_i = \frac{P'X_{ie}}{P'X_{it}} = \frac{EE_i}{TE_i} \tag{6}$$

2.3.2 Determinants of wheat farmers' efficiency

There are two methods for analyzing the source of efficiency of SFPF [24]. The 1st technique is a one-stage procedure in which the technical efficiency level and its driver are estimated simultaneously. The 2nd technique is a two-step procedure where in the 1st stage, the efficiency scores are computed; then, in the 2nd stage, the resulting efficiency scores are regressed using either the OLS method or Tobit regression. In this study, a two-stage estimation procedure with two-limit Tobit regression was employed to identify the determinants of efficiency since it allows the estimation of AE and EE in addition to TE [10, 25–27], unlike the one-stage approach, which permits the estimation of only the determinants of TE. Understanding the factors that influence wheat farmers' efficiency is an important segment of research that aims at tackling the problems encountered by farmers, promoting sustainable agriculture, and increasing the agricultural sector's competitiveness and resilience.

Accordingly, the two-limit Tobit model is formulated by following [28] as:

$$y_i^* = \beta_0 + \beta_j X_{ij} + \mu_i \tag{7}$$

where i refers to the *i*th farmer and y_i^* is the latent variable that indicates the level of TE, AE, or EE of the *i*th farmer. β_0 is the intercept while β_j are coefficients and μ_i is a random error term that is independently and normally distributed. X_{ij} are variables that affect the TE, AE, and EE of wheat producers and are presented in Table 2 below.

After denoting the observed dependent variable as y_i, the Tobit model can be written as

$$y_i = \begin{cases} 1 & if\ y_i^* \geq 1 \\ y_i^* & if\ 0 < y_i^* < 1 \\ 0 & if\ y_i^* \leq 0 \end{cases} \tag{8}$$

where y_i^* represents the efficiency score of the ith household. The likelihood function of the Tobit model is specified as:

$$L\left(\beta, \frac{\sigma}{y_j}, X_j, L_{1j}, L_{2j}\right) = \prod_{y=L_{1j}} \omega\left(\frac{L_{1j} - \beta' X_j}{\sigma}\right) \prod_{y_j=y_j^*} \frac{1}{\sigma} \varnothing\left(\frac{y_j - \beta' X_j}{\sigma}\right) \prod_{y_j=L_{2j}} 1 - \omega\left(\frac{L_{2j} - \beta' X_j}{\sigma}\right) \tag{9}$$

where L_{1j} and L_{2j} are the lower and upper bounds, respectively, while $\omega(.)$ = the cumulative normal distribution, φ (.) = the normal density function.

As indicated by [29, 30], the overall marginal effect (ME) of the Tobit model in Eq. (9) is divided into the following three MEs.

i. The unconditional expected value of wheat farmers' efficiencies

$$\frac{\vartheta E(y^*)}{\vartheta X_j} = [(Z_U) - (Z_L)] \frac{\vartheta E(y^*)}{\vartheta X_j} + \frac{\partial [(Z_U) - (Z_L)]}{\vartheta X_j} + \frac{\partial (1 - (Z_U))}{\vartheta X_j} \tag{10}$$

ii. The expected value of wheat farmers' efficiencies, which is conditional upon being between the limits

$$\frac{\vartheta E(y^*)}{\vartheta X_j} = \beta_m \left[1 + \frac{(Z_L(Z_L)) - (Z_U(Z_U))}{((Z_L) - (Z_U))}\right] - \left[\frac{(\omega(Z_L)) - (\omega(Z_U))^2}{((Z_L) - (Z_U))^2}\right] \tag{11}$$

iii. The probability of being between the mean value (A) and upper limit (U)

$$\frac{\vartheta [(Z_U) - (Z_A)]}{\vartheta X_j} = \frac{\beta_m}{\sigma} \left[\omega(Z_A) - (Z_U)\right] \tag{12}$$

where $Z_{L/A} = \frac{-\beta' X}{\sigma}$ and $Z_U = \frac{(1-\beta X)}{\sigma}$ are standardized variables that come from the likelihood function given the limits of y^*, and σ is the standard deviation of the model.

3 Results and discussion

3.1 Descriptive statistics

This study comprised 88.9% male-headed households of the 422 randomly selected wheat-producing farmers, with an average age of 46.22 years (Table 3). The mean household size in the study area is 4.88 persons (4.38 adult equivalent), which is consistent with the national average family size (4.6 person) [35], with an average education level of 7.01 years. The mean livestock holdings were 6.47 TLU, while the average land holdings were 2.45 hectares, which is greater than the national average livestock holdings of 2.7 TLU [36] and land holdings of 1.1 hectares [37]. Nearly 59.4% of the respondents used mechanization for wheat production, while 31.3% utilized credit. The mean distance from the main market was 7.08 km, and the average frequency of contact with the extension agent was 4.44 days per year. Nearly 66% of the respondents participated in off/nonfarm activities. The farmers produced 40.12 quintals of wheat, using, on average, 188.1 kg of seed, 13.79 man-days of labor, 8.97 oxen days, 236.14 kg of fertilizer, and 3.76 litters of agrochemicals from an average of 1.41 hectares of wheat land.

Table 3 Descriptive summary of variables. Source: Own estimation; 2024

Variables	Unit of measurement	Mean	Standard deviations
Sex of household head	Dummy (male = 1)	0.89	0.31
Age household head	Years	46.22	10.37
Education level	Years of schooling	7.01	3.46
Livestock holding	TLU	6.47	3.65
Family size	Adult equivalent (person)	4.38 (4.88)	1.69
Total farm size	Hectares (ha)	2.45	1.69
Mechanization	Dummy (yes = 1)	0.594	0.491
Credit	Dummy (yes = 1)	0.313	0.464
Extension contacts	Number of days per year	4.44	3.84
Market distance	KM	7.08	3.91
Off/nonfarm participation	Dummy (yes = 1)	0.66	0.47
Wheat output	Quintal	40.12	30.16
Land for wheat	Hectare	1.41	1.01
Labor	Man-day	13.79	9.49
Oxen	Oxen day	8.98	14.74
Chemical	Liters	2.72	1.78
Fertilizer	Kilogram	236.14	179.38
Seed	Kilogram	188.10	97.41

Table 4 GLR test of hypotheses for the stochastic production function. Source: Own estimation, 2024

Null hypothesis	Df	λ	Critical value	Decision
H_o:$\beta_{ij}=0$	21	26.88	32.67	Accept H_o
H_o:$\gamma=0$	1	22.39	3.84	Reject H_o
H_o:$\delta_1=\delta_2=\delta_3 \ldots \ldots .\delta_{10}=0$	11	41.37	18.307	Reject H_o

3.2 Efficiency of wheat producers

Before estimating the SFM, it is important to test the three-model specification-related hypotheses. The first test involved selecting either the CD or translog functional form, and a GLR test was performed. The results indicated that the coefficients of the translog production function were almost zero ($\boldsymbol{H_o}$:$\boldsymbol{\beta_{ij}}=0$), which confirmed that the CD functional form best fit the data at hand ($\boldsymbol{H_1}$:$\boldsymbol{\beta_{ij}}\neq 0$) (Table 4).

Then, the null hypothesis argues that the inefficiency component of the total error term is equal to zero ($H_o : \gamma=0$), and an alternative hypothesis ($H_1 : \gamma\neq 0$) was tested by calculating the GLR. The findings demonstrate that the null hypothesis that state wheat farmers in the study area are 100% efficient is not accepted. Another hypothesis to be tested was that all coefficients of the inefficiency model are simultaneously equal to zero (i.e., H_o:$\delta_1=\delta_2=\delta_3.....\delta_{10}=0$) against the alternative hypothesis, and a GLR test was performed. The findings confirmed the rejection of the null hypothesis, favoring the alternative hypothesis, which argues that the explanatory variables that affect wheat farmers' efficiency levels are not all equal to zero (Table 4).

The maximum likelihood of CD-SFPF was estimated after testing the above hypothesis. Here, the input variables were land under wheat (in hectares), the labor force in man-equivalent for wheat production (in man/days), oxen (oxen-days), the quantity of seed (kg), chemicals (herbicides and pesticides in liters), and fertilizer (both NPS and urea in kg), where the output variable was wheat yield (quintals) in the 2022/23 production year. For the estimate of the CD-SFPF, the model specification result is significant ($wald\ chi^2=3056.26$, prob > $chi^2=0.0000$), suggesting that at the 1% level of statistical error, the null hypothesis that states all slope coefficients are zero is rejected. Furthermore, sigma squared (σ^2), which is a diagnostic measure of the inefficiency component that confirms the quality of model estimation and the validity of the distributional form assumed for the composite error term, was statistically significant. The Gamma

Table 5 Maximum likelihood estimates of the wheat production function. Source: Own estimation, 2024

Variables	Coefficient	Std. Errs
ln(labor)	0.013	0.022
ln(land)	0.477***	0.066
ln(seed)	0.088***	0.032
ln(fertilizer)	0.311***	0.060
ln(pesticide)	0.130***	0.045
ln(oxen)	0.003***	0.001
Constant	1.456***	0.334
Lambda	1.810***	0.038
$Sigma^2$	0.110***	0.013
Gamma	0.766	
Log-likelihood	15.378	
Wald chi^2 (6)	3056.26***	

***Indicates significance at 1% levels of statistical error

coefficient ($\gamma = \sigma_u^2/\sigma^2$) is 0.766, indicating that technical inefficiency accounts for 76.6% of the wheat yield disparity at the frontier, while 23.4% is attributed to factors outside farmers' control (Table 5).

Table 5 presents the maximum likelihood parameter estimates of the CD-SFPF, and the results confirm that all inputs except labor were found to positively and significantly affect wheat output at a 1% level of statistical error. The model output indicated that a 1% increase in land, seed, fertilizer, chemical, and oxen days resulted in increases in wheat yields of 0.477, 0.088, 0.311, 0.130, and 0.003%, respectively, while all other factors remained constant.

The coefficients of inputs indicate the elasticity of output, which is summed to be 1.022, but this value does not guarantee the existing return to scale unless the hypothesis is tested. Accordingly, the hypothesis that farmers follow a constant return-to-scale was tested, which states that the sum of parameter coefficients is equal to 1 ($H_o : \beta_1 + \beta_2 + \beta_3 + \beta_4 + \beta_5 + \beta_6 = 1$) against the alternative hypothesis ($H_1 : \beta_1 + \beta_2 + \beta_3 + \beta_4 + \beta_5 + \beta_6 \neq 1$). The test results confirm the acceptance of the null hypothesis, indicating the presence of constant returns to scale among wheat farmers in the research area. This means that a 1% increase in all inputs would boost the overall wheat yield by approximately 1%.

The associated dual cost frontier function parameters are subsequently determined using the CD production function parameter listed below:

$$\begin{aligned} \ln TC_i = 1.949 + 0.118\left(\ln P_{Labor}\right) + 0.355\left(\ln P_{Land}\right) + 0.187\left(\ln P_{Seed}\right) \\ + 0.092\left(\ln P_{Chemical}\right) + 0.200\left(\ln P_{Fertilizer}\right) + 0.005\left(\ln P_{Oxen}\right) + 0.017\left(\ln Y^*\right) \end{aligned}$$

where P stands for the price of inputs which is measured in *Birr*[2] P_{Land} is the rental value of land per hectare for one year (Ludehetosa = 10,000 Birr, Digeluna Tijo = 15,000 Birr, and Dodota = 8000 Birr on average), and P_{oxen} is the price of paired oxen power that is estimated at 400 Birr/day. P_{Labor} is the wage rate of labor estimated at 200 Birr/day, $P_{Fertilizer}$ is the price of chemical fertilizer per kg estimated at Birr (urea = 36 Birr/kg and NPS = 42 Birr/kg), P_{Seed} is the price of seed (improved = 55 Birr/kg and local = 40 Birr/kg), and $P_{Chemical}$ is estimated at 1800 Birr/liter.

3.3 Wheat production efficiency scores and distributions

Table 6 summarizes the SFM outputs and indicates that the mean TE, AE, and EE of the wheat farmers were approximately 80.8%, 88.1%, and 71.3%, respectively. Of the total number of respondents, approximately 41.47%, 36.26%, and 42.18% had TE, AE, and EE scores below the average level, respectively. The highest mean TE (83.8%) and AE (87.2%) were recorded in the Ludehetosa District, while the lowest mean TE (74.9%) and AE (88.3%) were recorded in Dodota. On the other hand, the highest mean EE (73.3%) was recorded in Digeluna Tijo District, where the lowest was recorded again in Dodota (66.5%). The disparity in wheat efficiency among districts could be attributed to restricted water availability and erratic or insufficient rainfall in lowland (Dodota) areas compared to those in midland (Ludehetosa) and highland areas (Digeluna Tijo), as wheat requires appropriate moisture for proper cultivation.

[2] Birr is Ethiopian currency and 1 Birr is currently equivalent to 0.017 United States Dollars.

Table 6 Distribution of TE, AE, and EE. Source: Own estimation, 2024

Efficiencies range	Frequency			Percentage		
	TE	AE	EE	TE	AE	EE
0.31–0.4	2		11	0.47		2.61
0.41–0.5	4	2	12	0.95	0.47	2.84
0.51–0.6	5	5	36	1.18	1.18	8.53
0.61–0.7	42	21	99	9.95	4.98	23.46
0.71–0.8	105	33	163	24.88	7.82	38.63
0.81–0.900	207	136	97	49.05	32.23	22.99
0.91–1	57	225	4	13.51	53.32	0.95
Total	422	422	422	100	100	100
Min	0.318	0.442	0.310			
Max	0.964	0.991	0.941			
Std. Dev.	0.096	0.094	0.117			
Mean	0.808	0.881	0.713			
Operating below mean	175	153	178	41.47	36.26	42.18
Operating above mean	247	269	244	58.53	63.74	57.82
Districts						
Digeluna Tijo	0.828	0.886	0.733			
Ludehetosa	0.838	0.872	0.731			
Dodota	0.749	0.883	0.665			

The mean TE was 80.8%, with the lowest value of 31.8% and the highest value of 96.4%. This means that if farmers can acquire essential managerial and technical skills, on average, they can increase their output by 19.2% (100–80.8). This suggests that if the average wheat farmer maintains the same TE level as its most efficient farmer, it could reduce 16.18% (100–80.8/96.4) of the inputs required to produce the maximum possible output.

The average AE was 88.1%, with the lowest value of 44.2% and the highest value of 99.1%, suggesting that wheat farmers may save 11.9% (100–88.1) of their present input costs if resources are used efficiently. This demonstrates that wheat farmers with an average AE score may reduce production costs by 11.09% (100–88.1/99.1), which is necessary to achieve the level of the most allocatively efficient wheat farmers by cost-effectively reallocating resources.

The mean EE score is 71.3%, with the lowest value of 31.0% and the highest value of 94.1%. This implies that wheat producers with average EE can reduce the existing average costs by 29.4% (100–71.3) to obtain the lowest possible production cost while maintaining the same level of wheat yield. The results also suggested that wheat farmers with an average EE would reduce their average costs of production by 24.22% (100–71.3/94.1) to achieve the most economically efficient production.

3.4 Determinants of wheat farmers' efficiency

In this study, to identify the factors that affect wheat farmers' TE, AE, and EE, a two-limit Tobit model was estimated. Before estimation, diagnostic tests were carried out, and the findings verified that there were no serious econometric problems with the data at hand. Tobit regression was used (Table 7), and the results revealed that livestock ownership, household head age, education level, engagement in off/nonfarm activity, and contact with agricultural extension agents had a positive and significant effect on TE, whereas total farm size and distance from the main market had a negative impact. Similarly, wheat producers' AE increased considerably with family size, frequency of extension contacts, and wheat mechanization, and decreased with distance from the main market. It has also been specified that education level, off/nonfarm activity engagement, extension contact, and wheat mechanization have a positive and substantial effect on EE, while total farm size and distance from the main market have a negative impact.

The model output indicates that farmers' age, which is a good predictor of agricultural experience, enhances the TE of wheat producers at a 1% level of statistical error. The ME estimation indicates that a 1-year increase in the age of the household head results in a 0.10%, 0.10%, and 0.50% increase in the level of TE, the expected value of TE, and the

Table 7 Summary of two-limit Tobit regression results. Source: Own estimation, 2024

Covariates	TE		AE		EE	
	Coefficient (Std. error)	ME	Coefficient (Std. error)	ME	Coefficient (Std. error)	ME
Age	0.0011*** (0.0004)	0.001	−0.0006 (0.0005)	−0.0005	0.0004 (0.0006)	0.0004
		0.001		−0.0004		0.0004
		0.005		−0.0016		0.0017
Education	0.0021* (0.0012)	0.002	0.0010 (0.0013)	0.0009	0.0024* (0.0014)	0.0024
		0.0019		0.0007		0.0023
		0.0098		0.0026		0.0098
TLU	0.0033** (0.0013)	0.0032	−0.0012 (0.0013)	−0.0011	0.0019 (0.0015)	0.0019
		0.0029		−0.0008		0.0018
		0.0153		−0.0032		0.0077
Market distance	−0.0033*** (0.0010)	−0.0032	−0.0039*** (0.0014)	−0.0035	−0.0059*** (0.0013)	−0.0058
		−0.0029		−0.0028		−0.0056
		−0.0153		−0.0107		−0.0234
Extension contact	0.0020* (0.0011)	0.002	0.0024** (0.0010)	0.0021	0.0035** (0.0017)	0.0035
		0.0018		0.0017		0.0033
		0.0094		0.0065		0.0139
Total land holding	−0.0074** (0.0031)	−0.0073	−0.0023 (0.0029)	−0.0021	−0.0083** (0.0037)	−0.0083
		−0.0067		−0.0017		−0.0079
		−0.0348		−0.0065		−0.0332
Family size	−0.0006 (0.0025)	−0.0005	0.0062*** (0.0023)	0.0056	0.0044 (0.0029)	0.0044
		−0.0005		0.0045		0.0042
		−0.0026		0.0172		0.0175
Mechanization	0.0095 (0.0085)	0.0093	0.0589*** (0.0105)	0.0537	0.0569*** (0.0110)	0.0565
		0.0085		0.0435		0.054
		0.0444		0.1656		0.2236
Credit utilization	−0.0047 (0.0081)	−0.0046	0.0128 (0.0082)	0.0116	0.0063 (0.0094)	0.0063
		−0.0042		0.0092		0.006
		−0.0218		0.0346		0.0251
Off/nonfarm participation	0.1102*** (0.0079)	0.1084	0.0058 (0.0089)	0.0053	0.1009*** (0.0115)	0.1002
		0.1014		0.0042		0.0965
		0.4669		0.0163		0.3811
Constant	0.6798*** (0.0265)		0.8611 (0.0334)		0.5872 (0.0345)	

***, **, and * indicate 1%, 5%, and 10% levels of statistical errors, respectively. The MEs represent the total change $\left[\frac{\partial E(y)}{\partial Xj}\right]$, expected change $\left[\frac{\partial E(y*)}{\partial Xj}\right]$, and probability change $\left[\frac{\partial\left[\emptyset(Z_U)-\emptyset(Z_A)\right]}{\partial Xj}\right]$

likelihood of a household scoring above the mean TE, respectively. This result is in line with the findings of [10, 13], who identified the age of households as a key determinant of agricultural production efficiency. This may be because as the household head's age increases, farm knowledge accumulated through experience also increases. This helps to make better agricultural decisions and enhances resource management practices in wheat production through better on-farm risk mitigation strategies, which improves wheat production efficiency.

The education level of the household head was found to have a positive and significant effect on the TE and EE of wheat farmers at the 10% level of statistical error. As education level increases by 1 year of schooling, the level, expected value, and likelihood of scoring above the mean value of TE increase by 0.20%, 0.19%, and 0.98%, respectively, while the overall level of EE, the expected value of EE, and the probability of scoring above the mean value of EE increase by 0.24%, 0.23%, and 0.98%, respectively. The same result was also reported by [10, 13, 14], who confirmed the positive role of education in enhancing agricultural production efficiency. This could be because well-educated farmers have greater access to information and can easily comprehend farm instructions since education increases farmers' consciousness over the need to acquire, analyze, and apply knowledge that increases wheat production efficiency.

Livestock holding in TLU was among the positively significant variables that determined the TE of wheat farmers at a 5% level of statistical error. This implies that households with higher livestock ownership are expected to have better wheat TE. As livestock holdings increased by 1 TLU, the overall level of TE increased by 0.32%, while the expected value of TE increased by 0.29%, and the probability of a household scoring above the mean TE increased by 1.53%. The positive role of holding livestock was expected since it is a good proxy for the wealth of farm households. A similar result was reported by [11, 25], as livestock provide additional income, and traction power for crop cultivation, which is expected to enhance wheat production efficiency.

The model results also confirm that farmers' residence distance from the major market was inversely correlated with all efficiency estimates (TE, AE, and EE) at the 1% level of statistical error. This implies that as farmers get closer to the main market, from where they purchase farm inputs and sell their products, they will be more efficient than other farmers. This result is consistent with the findings of [10, 25, 32], who reveal a negative role for farm residence distances from the main market. This may be because, as farmers are closer to the market, they are more likely to experience lower expenses associated with marketing transactions.

The coefficient of the total farm size was negative and significantly affected both TE and EE at a 5% level of statistical error. This indicates that as total land holdings increase, the level of wheat farmers' TE and EE decreases. A study by [13, 25] also confirmed the negative association between landholding and production efficiency, even if the land is an important economic variable that enhances household income by increasing production volume. However, farm size is inversely related to the efficiency level of particular crops since it challenges farm management practices and resource distribution, and smaller landholdings tend to have better management practices and ease the administration of production inputs, which can result in a more effective wheat production system.

The model results confirm that farmers' contact was positively associated with TE, AE, and EE at the 10%, 5%, and 5% levels of statistical error, respectively. This implies that wheat producers with a greater frequency of contact with agricultural extensions are expected to have better wheat production efficiency. A study by [10, 11] also confirmed the positive role of agricultural extension contact on the efficiency of agricultural production. This may be because agricultural extension centers are the primary source of agricultural information that helps farmers become more informed and proficient, which enhances their farming methods and productivity. In addition, extension agents facilitate and promote the adoption of improved agricultural practices that contribute to the efficiency of agricultural production.

Family size was found to have a positive and significant effect on wheat farmers' AE at the 1% level of statistical error. This suggests that households with larger families are more likely to have better AE than others. As family size increased by one adult equivalent, the overall level of AE, the predicted value of AE, and the likelihood of scoring above the mean of AE increased by 0.56%, 0.45%, and 1.72%, respectively. This outcome was expected given that family size is a significant source of family labor, which is consistent with previous research [11, 25]. As labor availability increases, agricultural activities that require an intensive labor force will perform well, and the adoption of agricultural technology will also be enhanced [38, 39], which is expected to increase the production efficiency of wheat farmers.

Wheat mechanization is another important factor that positively and significantly affects both AE and EE at the 1% level of statistical error. This implies that households that utilize machinery for wheat production are expected to have greater wheat production efficiency than nonusers. The findings of [33, 34] also support the positive role of mechanization in agricultural development through enhancing production and productivity. This may be because mechanizing wheat production improves farmers' efficiency by lowering labor costs, shortening the length of plowing and harvesting, and reducing postharvest losses.

Household head participation in off/nonfarm activities was also found to significantly and positively affect both TE and EE at the 1% level of statistical error. This suggests that households engaged in off/nonfarm activities are predicted to have greater TE and AE levels than their counterparts (those who have not participated). The same result was reported by [10, 25], which may be because off/nonfarm activity increases household income and secures diversified income sources that reduce risks. This contributes to the purchase of farm inputs such as improved seeds and fertilizer and enhances the adoption of improved agricultural technologies that increase production efficiencies.

4 Conclusion and policy implications

As Ethiopian wheat production is undergoing a revolution and agricultural production is dynamic, understanding the current level of wheat production efficiency and knowing its determinants are important. Accordingly, the SFM and a two-limit Tobit model were employed to identify wheat farmers' efficiencies and their drivers, respectively. The results indicated that the average TE, AE, and EE values were 80.8%, 88.1%, and 71.3%, respectively, indicating that wheat farmers are working below the maximum attainable efficiency levels. These data imply that there is space for improving the TE, AE, and EE of wheat farmers in the Arsi zone at given levels of inputs and production technologies. The two-limit Tobit model results show that age, education, livestock holdings, contact with agricultural extension agents, family size, wheat mechanization, and non/off-farm participation enhance the efficiency of wheat producers, while the distance from the main market and total land holdings reduce their efficiency.

Finally, to improve wheat farmers' efficiency and attain the national objective of wheat self-sufficiency, it is critical to encourage policies and strategies that increase access to education through skilled educators and an appropriate learning environment. It is also essential to promote livestock production, which may be achieved by encouraging consistent animal feed production and providing efficient veterinarian services. Furthermore, it is necessary to boost wheat mechanization through subsidies and financial assistance. In addition, to enhance wheat production efficiency, market development and an environment that encourages farmers' diverse income streams must be promoted through improved infrastructure and credit provisions.

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Declarations

Ethics approval and consent to participate This research was approved by the Economics Department of the College of Business and Economics at Arba Minch University in accordance with the ethical standards of Arba Minch University research guidelines. Then voluntary, verbal, and informed consent was obtained from all participants by explaining the study objectives and the confidentiality of their responses.

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