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Economic Efficiency and Productivity of Smallholder Teff Producers in Awabel District of East Gojjam Zone in Ethiopia

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Abstract

Improving agricultural resource-use efficiency is essential for advancing sustainable food systems, reducing rural poverty, and strengthening the contribution of smallholder agriculture to the Sustainable Development Goals (SDGs), particularly SDG 1 (No Poverty), SDG 2 (Zero Hunger), and SDG 12 (Responsible Consumption and Production). In Ethiopia, where despite the profound cultural, nutritional, and economic dominance of teff(Eragrostis tef), farm-level productivity faces major structural bottlenecks within the East Gojjam Zone. This study investigates the technical, allocative, and overall economic efficiencies among smallholder teff farmers in Awabel District, East Gojjam zone, as well as their underlying socio-economic and institutional determinants.A two-stage stratified random sampling technique was used to survey 360 target household heads across various agro-ecological strata. By employing a parametric Stochastic Frontier Analysis (SFA) framework to isolate manageable internal inefficiencies from random environmental noise, the econometric results show that teff cultivation operates under decreasing returns to scale, with cultivated land size emerging as the dominant frontier driver of output expansion.Yields are greatly and favorably impacted by both contemporary materials like chemical fertilizers and pesticides as well as inputs like labor and oxen. Ultimately, the mean technical, allocative, and economic efficiency scores are estimated at 82.45%, 75.63%, and 63.79%, respectively, showing that structural cost distortions and allocative failures represent the primary barriers to financial optimization. Inefficiency modeling shows that formal education, practical farming experience, extension contacts, targeted training, microcredit access, livestock holdings, and favorable weather conditions significantly minimize economic inefficiency. Policymakers should concentrate on stabilizing localized land rental registries, expanding credit mechanisms to address seasonal cash starvation, and shifting public extension networks toward management-capacity building.

1. Introduction

Ethiopia's economy is still structurally depends on agriculture, which employs the majority of rural workers and accounts for more than 35% of the country's GDP [1]. Over 90% of all arable land is managed by smallholder farmers in this main sector, most of whom work on a subsistence basis[2]. However, these production systems are severely degraded, heavily dependent on unpredictable rainfed regimes, and have minimal physical capital accumulation [3]. Therefore, ensuring food self-sufficiency, reducing structural poverty throughout agrarian communities, and accelerating broad-based rural development all depend on optimizing smallholder agricultural output within these limited frameworks[4], [5].

Around 75% of Ethiopia's total cultivated land is used for cereal crops, which are the main source of food expenditures for rural households[6]. Due to its unparalleled land coverage, high market value, and strong cultural preference, teff (Eragrostis tef) is particularly important among these cereals [7]. Teff is a staple crop and a vital source of income because to its agronomic resistance to water logging, structural storage lifespan, and superior nutritional qualities [8]. It serves as the foundation for injera, the national flatbread that powers the food exchange between rural and urban areas [9].

National teff yields are still fundamentally poor despite the crop's economic significance; they typically fall well short of the genetic and agronomic potential of the crop as shown in controlled experimental research trials [10]. Due to poor management and a lack of institutional assistance, smallholders continue to work substantially below their optimal production frontiers, which results in massive output gaps [11]. For households with limited resources, enhancing economic efficiency is a more financially feasible option, even though traditional policy

models place a strong emphasis on increasing physical input delivery [12]. Given current technology and input pricing, economic efficiency, which includes technical and cost-minimizing allocative configurations, measures a farm's actual capacity to maximize output [13]. According to [14], resource optimization prevents dependency on unsustainable horizontal land growth.

Large-scale structural inefficiencies among smallholder cereal producers in different regional states are highlighted by empirical border-based studies [15]. With mean technical efficiency scores frequently indicating unexploited output gaps above 23% under similar technology sets, stochastic frontier analyses show significant performance differences [16], [17]. A complex combination of institutional and socioeconomic factors directly influences these efficiency levels [18]. Operational capability is systematically improved by having access to formal education, long-term farming experience, and regular extension contact [19]. On the other hand, resource misallocation is exacerbated by severe financial limitations, remote output markets, high household dependency ratios, and fragmented plot layouts, which drive smallholders away from the ideal production frontier [20].

Adoption of modern agronomic packages, like row planting, chemical fertilizers, and certified seed types, is closely linked to improved farm performance [21]. Crop yields and farm profit margins are greatly increased by using these revised technical configurations [9]. However, household asset ownership, institutional liquidity, and accessibility to infrastructure all significantly influence the returns on these technological investments [6]. Due to allocative imbalances when matching costly inputs with varying market prices, resource-constrained smallholders frequently miss out on full profits [22]. To find underlying technological issues, it is therefore essential to examine how these technology adoption patterns combine with localized operating settings.

Vertical efficiency gains are the only feasible development pathway because horizontal area expansion is unachievable due to growing population constraints and shrinking farm sizes [23]. Additionally, the stability of smallholders is being threatened by new macroeconomic shocks, changes in rainfall brought on by climate change, and unstable input pricing [24]. Context-specific empirical data are desperately needed for localized planning because regional or zonal aggregations obscure micro-level differences [25]. By methodically assessing the economic efficiency and productivity of smallholder teff producers in Awabel District, this study fills a vital knowledge gap to provide data-driven insights for local agricultural authorities, directly supporting SDG 1 (No Poverty), SDG 2 (Zero Hunger), and SDG 12 (Responsible Consumption and Production) through targeted extension initiatives and optimized resource utilization. The remainder of the paper is organized as follows. The data and estimation techniques are described in Section two; the results are reported and discussed in Section three; Conclusions and policy proposals are presented in Section four. The references come next.

2. Methods and materials

Awabel District is located in the East Gojjam Zone of the Amhara Regional State. It is bordered by Gozamen District to the west, Debay Telategen to the north, Aneded and the Abay Gorge to the south, and Dejen District to the east. The district's administrative town, Lumame, is situated 259 km from Addis Ababa, 306 km from Bahir Dar, and 40 km from Debre Markos. According to CSA (2007), Awabel has a total population of 147,431, of which 126,794 reside in rural areas. The district covers 787.22 km², with 75% plateau and 25% mountainous terrain. Its agro-ecology comprises 60% Woina Dega, 25% Kola, and 15% Dega zones. Annual rainfall ranges between 1100–1400 mm, with temperatures from 7.5°C to 25°C. The soil types include 55% Vertisol, 30% Nitosol, and 15% Cambisol. Of its 28 kebeles, 25 are rural, and about 89% of the population depend on rain-fed, mixed subsistence farming.

Source: A geographic information system (GIS), 2025.

The purpose of this study was to use both descriptive and inferential methods to identify and characterize the factors influencing economic efficiency of teff productivity in Awabel District. To gather comprehensive information regarding farmers' production methods and socioeconomic circumstances, both quantitative and qualitative cross-sectional data were gathered. The study's objectives were addressed using a descriptive research approach, and the impacts of explanatory variables on teff productivity among smallholder farmers were estimated using the Cobb-Douglas production function. Structured questionnaires and in-person interviews self-administered for literate respondents and interviewer-administered for illiterate participants were used to gather primary data. All farmers who produced teff were included in the target population, which was selected from lists supplied by agricultural offices and cooperatives. A stratified random sampling method was used to ensure representativeness based on agro-ecological zones Dega, Woina Dega, and Kola. From 28 kebeles, five were randomly selected: three from Woina Dega, one from Kola and one from Dega. Finally, 360 sample farmers were selected from a total of 5,745 teff farmers using [26] formula, with a 5% margin of error and a 95% confidence level, ensuring the reliability and validity of the sample.

Awabel district has 28,630 farm households. Of the total population, 5,745 live in the five rural kebeles in 2025/2026 (District population projection, 2025). Therefore, the sample size should be:

$$n = \frac{z2.\ p.(1-p).N}{e2(N-1)+\ z2.p.q} = \frac{(1.96)2(.\ 0.5).(1-0.5).(5{,}745)}{(0.05)2(5{,}745-1)+(1.96)2.(0.5).(0.5)} = 360.13\sim360$$

Table 1
Proportional sample size determination

No.	Kebele name	Number of populations	Sample size
1.	Duke	1080	68
2.	Yesenbet	1207	75
3.	Tsidmariam	1074	67
4.	Dintamariam	1145	72
5.	Wojjelankerak	1239	78
	Total	5745	360

Methods of Data Analysis

For this study, both descriptive and econometric methods were employed. Descriptive statistics such as means, percentages, ratios, and standard deviations were used to summarize the socioeconomic characteristics of sample farmers, input-output variables, and efficiency distributions, providing a clear understanding of the data before econometric estimation.

Farm-level technical and allocative efficiencies were estimated for the econometric analysis using the Stochastic Frontier Production Function (SFPF). Because it takes into account both inefficiency effects and random shocks like weather variations, conflict disruptions, pest and disease outbreaks, and measurement errors, the stochastic frontier approach was chosen. It distinguishes random noise from the inefficiency component, in contrast to deterministic methods like Data Envelopment Analysis (DEA). In accordance with [28] and [27], the model splits

the error term into two components, one of which represents technical inefficiency and the other of which captures uncontrollable random disturbances.

According to [29], the economic efficiency of a production unit consists of two components: technical efficiency (TE) and allocative efficiency (AE). Technical efficiency measures the ability of a farm to obtain maximum output from a given set of inputs whereas, Allocative efficiency reflects the ability of a farm to use inputs in optimal proportions given their prices and the production technology. The product of these two components yields economic efficiency (EE):

$EE_i=TE_i \times AE_i$

Where;EE_i ranges between 0 and 1. A value of 1 indicates full efficiency, while values less than 1 indicate inefficiency.

The stochastic production frontier model is specified as:

$Y_i = f(X_i;\beta) \exp(V_i - U_i)$

Where; $Y_i$is the output of the i^{th} farmer, X_i represents the vector of inputs, and β denotes parameters to be estimated. The random error term V_i captures statistical noise and is assumed to be independently and identically distributed as $N(0,\sigma_v^2)$ while U_i represents non-negative inefficiency effects, assumed to follow a half-normal distribution $N+(0,\sigma_u^2)$.

To determine the appropriate functional form for the empirical frontier, a Likelihood Ratio (LR) test is conducted to compare the Cobb–Douglas and Translog specifications. The log-linear form of the Cobb-Douglas production frontier is specified as:

$\ln Y_i = \beta_0 + \sum_{j=1}^{k} \beta_j \ln X_{ij} + V_i - U_i$

While the Translog production frontier specification is written as:

$\ln Y_i = \beta_0 + \sum_{j=1}^{k} \beta_j \ln X_{ij} + \frac{1}{2} \sum_{j=1}^{k} \sum_{m=1}^{k} \beta_j \ln X_{ij} \ln X_{im} + V_i - U_i$

The technical inefficiency effect (U_i) is explicitly modeled as a function of environmental, demographic, and institutional variables:

$U_i = \delta_0 + \sum_{r=1}^{m} \delta_r Z_{ir} + w_i$

Where:$Z_{ir}$is a vector of explanatory variables affecting farm inefficiency, $\delta_r$represents the parameters to be estimated, and w_i is a random error term defined by the truncation of the normal distribution. A negative sign on an estimated $\delta_r$coefficient indicates that the respective variable reduces inefficiency.

The technical efficiency (TE_i) of each farmer is calculated as the ratio of observed output to the corresponding frontier output:

$TE_i = \exp(-U_i)$

Using the parameter estimates from the production frontier, the dual cost frontier is specified to isolate cost inefficiency (U_{ic}):

$$\ln C_i = \alpha_0 + \alpha_1 \ln Y_i + \sum_{j=1}^{k} \alpha_j \ln P_{ij} + V_{ic} + U_{ic}$$

Where C_i is the total cost of production for farmer i, Y_i is the output level, P_i is the vector of input prices, α is a vector of parameters to be estimated, V_{ic} is the random error representing statistical noise, and U_{ic} is the non-negative cost inefficiency component. Allocative efficiency is defined as the ratio of predicted minimum cost to the actual observed cost:

$$AE_i = \frac{C_i^{min}}{C_i} = \exp(-U_{ic})$$

The total economic efficiency (EE_i) is the product of the two measures:

$$EE_i = TE_i * AE_i$$

Table 2
Description, Measurement, and Expected Signs of Variables

Variable Category	Variable Name	Measurement & Description	Expected Sign	Econometric Placement
Dependent Variables	Teff Output (Y_i)	Continuous: Total yield produced per farm (in Quintals).	N/A	Dependent Variable in Production Frontier
	Total Cost (C_i)	Continuous: Sum of all cash expenditures and imputed values of inputs (Ethiopian Birr).	N/A	Dependent Variable in Cost Frontier
Production Inputs (Quantities)	Farm Land Size	Continuous: Total land area allocated to Teff (hectares).	+	Production Frontier
	Labor	Continuous: Total labor used, measured in man-days (family + hired).	+	Production Frontier
	Oxen	Continuous: Total oxen-days used for land preparation and trampling.	+	Production Frontier
	Fertilizer	Continuous: Total quantity of chemical fertilizer applied (kg).	+	Production Frontier
	Improved Seed	Continuous: Total quantity of improved teff seed varieties used (kg).	+	Production Frontier
	Pesticide	Continuous: Total volume of chemical pesticides applied (liters).	+	Production Frontier
Input Prices	Price of Land	Continuous: Rental price of land per hectare in the locality (Birr).	+	Cost Frontier
	Wage Rate	Continuous: Prevailing daily wage rate per man-day in the village (Birr).	+	Cost Frontier
	Price of Oxen	Continuous: Rental rate of a pair of oxen per day (Birr).	+	Cost Frontier
	Price of Fertilizer	Continuous: Average cost of fertilizer per kilogram (Birr).	+	Cost Frontier
	Price of Seed	Continuous: Average price of teff seed per kilogram (Birr).	+	Cost Frontier
	Price of Pesticide	Continuous: Average price of pesticides per liter (Birr).	+	Cost Frontier
Demographic Factors	Educational Level	Dummy: 1 if the household head is literate; 0 otherwise.	-	Inefficiency Model
	Gender	Dummy: 1 if the household head is male; 0 if female.	+/-	Inefficiency Model
	Farm Experience	Continuous: Total number of years the respondent has been farming.	-	Inefficiency Model

Variable Category	Variable Name	Measurement & Description	Expected Sign	Econometric Placement
	Livestock Holding	Continuous: Total number of livestock owned, measured in Tropical Livestock Units (TLU).	-	Inefficiency Model
Institutional Factors	Extension Service	Dummy: 1 if the farmer has access to agricultural extension; 0 otherwise.	-	Inefficiency Model
	Market Information	Dummy: 1 if the farmer has access to timely market information; 0 otherwise.	-	Inefficiency Model
	Access to Training	Dummy: 1 if the farmer attended training; 0 otherwise.	-	Inefficiency Model
	Access to Credit	Dummy: 1 if the farmer has access to credit services; 0 otherwise.	-	Inefficiency Model
	Cooperative Member	Dummy: 1 if the farmer is a member of an agricultural cooperative; 0 otherwise.	-	Inefficiency Model
Environmental Factors	Weather Condition	Dummy: 1 if seasonal weather was favorable; 0 otherwise.	+/-	Inefficiency Model

3. Results and Discussions

3.1 Descriptive Results and Discussion

Table 3
Descriptive Statistics of Dummy Variables

Variable & Category		Frequency	Percentage (%)	Cumulative (%)
Gender	Female	57	15.83	15.83
	Male	303	84.17	100.00
Educational Level	Illiterate	144	40.00	40.00
	Literate	215	59.72	100.00
Extension Service	No Access	101	28.06	28.06
	Has Access	258	71.67	100.00
Market Information	No Access	174	48.33	48.33
	Has Access	185	51.39	100.00
Access to Training	No Access	200	55.56	55.56
	Has Access	159	44.17	100.00
Access to Credit	No Access	211	58.61	58.61
	Has Access	148	41.11	100.00
Cooperative Membership	Non-member	182	50.56	50.28
	Member	178	49.44	100.00
Weather Condition	Unfavorable	81	22.50	22.50
	Favorable	278	77.22	100.00
Source: field Survey 2025				

The 360 respondents' demographic and socioeconomic profile shows a sample that is largely composed of men (84.17%) and those with just rudimentary literacy (59.72%). Regarding institutional support, a sizable majority (71.67%) has access to agricultural extension services, and the distribution of cooperative membership (49.44%) and market information access (51.39%) is fairly balanced. Critical resource shortages still exist, nevertheless, as over half of the respondents do not have access to credit facilities (58.61%) and formal training (55.56%). Lastly, the vast majority of participants (77.22%) reported favorable environmental conditions despite these structural challenges, indicating that although institutional resource constraints such as credit and training are common, the seasonal baseline climate was favorable for the majority of respondents (Table 3).

Table 4
Descriptive Statistics of Production and Socio-Economic Variables

Variable Category & Definition	Mean	Std. Dev.	Std. Err.	t-statistic
Production Outcomes & Costs				
Crop Yield (quintals)	56.15	21.09	1.91	37.22***
Total Production Cost (ETB)	76,783.81	36,630.54	1,930.60	39.77***
Input Quantities				
Land Size (hectares)	2.43	1.22	0.06	37.91***
Labor Input (man-days)	137.21	64.48	3.40	40.38***
Oxen (days)	56.01	26.58	1.40	39.98***
Fertilizer Used (kg)	289.49	155.81	8.21	35.25***
Seed Quantity (kg)	79.10	37.92	2.00	39.57***
Pesticide Vol. (liters)	3.44	2.18	0.11	29.92***
Input Prices (ETB)				
Rental Price of Land (per ha)	15,519.72	563.26	29.69	185.94***
Wage Rate of Labor (per man-day)	189.71	23.14	1.22	155.55***
Rental Price of Oxen (per day)	361.68	46.59	2.46	147.30***
Price of Fertilizer (per kg)	79.76	6.56	0.59	169.96***
Price of Seed (per kg)	70.23	8.44	0.44	157.96***
Price of Pesticide (per liter)	446.90	52.79	2.78	160.64***
Socio-Economic Attributes				
Farming Experience (years)	26.87	13.26	0.70	38.45***
Livestock Holding (TLU)	8.08	3.88	0.20	39.54***
*** indicate statistical significance at the 10%, 5%, and 1% levels, respectively				
Source: Field survey 2025				

An average crop yield of 56.15 quintals per hectare household is shown by the collected data, indicating multi-crop systems or intense, high-yielding cultivation. However, a significant standard deviation of 71.09 quintals indicates that agricultural performance is extremely uneven. This large dispersion shows a stark contrast between high-performing operations and a sizable percentage of farms that are experiencing significantly lower levels of productivity. In the end, this considerable variability highlights significant differences between the families studied in terms of soil fertility, management techniques, exposure to the climate, and availability of vital agricultural inputs.

Households have to make significant financial commitments in order to attain these yields, with an average Total Production Cost of 76,783.81 ETB. This high number reflects a move away from low-cost subsistence farming

toward a considerable reliance on market-purchased inputs and hired resources, highlighting the substantial capital needed to maintain smallholder operations. However, with a standard deviation of 36,630.54 ETB, expenditures show a broad variation. This striking disparity shows how households' operational financial scales vary greatly. The cost difference points to a glaring economic division in the community, dividing wealthier, commercially focused producers who aggressively spend money to enhance their agricultural output from resource-poor farmers who must limit expenses out of need.

Despite significant disparities in land distribution, sampled households manage a relatively generous average land size of 2.43 hectares, placing them slightly above the critical fragmentation threshold and enabling the generation of marketable surpluses. Land continues to be the fundamental asset in agricultural production. This sample's production is quite labor-intensive, requiring an average of 137.21 man-days every cycle for necessary manual chores, and it heavily relies on conventional tillage, which uses an average of 56.01 oxen-days. Additionally, an average fertilizer consumption of 289.49 kg roughly 119 kg per hectare as well as an average application of 79.10 kg of seeds and 3.44 liters of pesticides demonstrate how deeply modern material inputs are integrated into the farming system. Significant standard deviations for each of these inputs demonstrate distinct intra-community variations in resource endowment, asset ownership, and household liquidity, which ultimately result in unequal access to yield-enhancing technologies on various operational scales.

High consistency and market stability across regional assets and commercial commodities describe the economic and input price environment in the research area. The average rental price of land is 15,519.72 ETB per hectare, suggesting a highly competitive or institutionalized localized rental market constrained by geographic norms. With a mean wage rate of 189.71 ETB per man-day, the agricultural labor market also has excellent wage constancy, indicating balanced labor dynamics and effective information flow.Similarly reliable, Oxen prices average 361.68 ETB per oxen-day, which helps asset-poor farmers avoid financial uncertainty during the critical pre-planting stage. The average price of chemical fertilizer is 79.76 ETB per kg, indicating institutional oversight and cooperative-led distribution that protects smallholders from localized price gouging. Commercial goods also exhibit strong pricing standardization. Lastly, pesticide prices show a wider dispersion around a mean of 446.90 ETB per liter, which is logically driven by the variety of chemical compositions and brand options available in the crop protection market, whereas improved seeds show a tight, standardized pricing structure averaging 70.23 ETB per kg.

3.2 Econometrics results

3.2.1 Estimation of Production and Cost Function

Table 5
Estimation of Cobb-Douglas frontier production function

Variable	Coefficient	Std. Err.	P > z	[95% Conf.Interval]
ln(land size)	0.5028936***	.0751696	0.000	.3555639.6502233
ln(labour-man day)	0.1099466**	.0527993	0.037	.0064618.2134314
ln(oxen)	0.11273***	.0414836	0.007	.0314235.1940364
ln(Fertilizer)	0.1150157***	.0345444	0.001	.04731.1827214
ln(improved seed)	0.0607499	.0601794	0.313	− .0571995.1786994
ln(pesticide)	.0625386***	.0225775	0.006	.0182874.1067897
Constant	3.35471***	.3602028	0.000	2.6487254.060695
ln(σ_v^2)	-4.922697***	.2747653	0.000	-5.461227-4.384167
ln(σu^2)	-2.341403***	.1201815	0.000	-2.576954-2.105851
σ_v	.0853198	.0117215		.0651793.1116838
σ_u	.3101494	.0186371		.2756904.3489155
σ^2	.1034721	.0105624		.0827701.1241741
λ $(\raisebox{1ex}{\$}\sigma_u\$/\raisebox{-1ex}{\$}\sigma_v\$)$	3.635138	.0270398		3.5821413.688135
LR test ofσ_u=0: chibar2(01) = 52.22			Prob > = chibar2 = 0.000	
Wald chi2(6) = 4278.91			Number of observations = 360	
Log likelihood = 79.182123			Prob > chi2 = 0.0000	
** And *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively Source: Model output 2025				

According to the empirical diagnostic statistics, the estimated Cobb-Douglas stochastic frontier model is reliable and very suitable for the data. The Wald chi2(6)value of 4278.91 ($p < 0.001$) indicates that the explanatory variables are jointly and highly significant in explaining variations in agricultural output, while the Likelihood Ratio (LR) test (chi2 = 52.22, $p < 0.001$) strongly rejects the null hypothesis of zero technical inefficiency, confirming that a conventional OLS model is inadequate and the SFA framework is statistically required. This is further supported by the lambda parameter (λ = 3.64), which shows that the variance from technical inefficiency (σ_u) significantly outweighs that of random idiosyncratic shocks (σ_v). This shows that manageable management inefficiencies, rather than uncontrollable factors like weather or pests, are the main cause of the shortfall in realized smallholder output.

The model is specified in a log-log Cobb-Douglas framework, the derived coefficients stand for direct production elasticities. The sampled farms show declining returns to scale, as indicated by the scale elasticity of 0.963 obtained from adding these inputs. This structural feature closely matches empirical data from modern Ethiopian agrarian economies and is particularly common for fragmented smallholder agricultural systems experiencing severe capital restrictions [30]. A 1% increase in cultivated area results in a 0.50% rise in agricultural output, making land sizes the frontier driver with the greatest influence. According to regional research highlighting land-driven agricultural expansion, this substantial elasticity highlights land availability as the main constraining limitation to output increase [25].

The production frontier is greatly influenced by traditional labor and oxen in addition to land. Agricultural output increases by about 0.11% for every 1% increase in labor man-days and oxen traction. This positive elasticity emphasizes how labor-intensive smallholder farming and how important oxen power is to timely field preparation and ideal crop planting[31]. Modern chemical inputs are crucial at the same time; teff production increases by 0.12% for every 1% increase in commercial fertilizer application. This significant recovery demonstrates that chemical fertilizers are still essential for replenishing depleted soil nutrients and moving the boundary uphill in the highlands of East Africa [25].

Within the predicted frontier, seed technology and chemical crop protection have different effects. A 1% increase in application increases realized output by 0.06% by reducing detrimental pre-harvest insect losses, according to pesticides' positive and statistically significant elasticity. Improved seed varieties, on the other hand, do not significantly increase productivity. Economically speaking, this surprise insignificance frequently results from smallholders' extensive reliance on subpar recycled seeds or from a lack of complementing inputs like irrigation and extension advice, which keeps high-yielding varieties from reaching their full genetic potential. This pattern is consistent with previous agricultural studies that point out that predicted efficiency gains are sometimes undermined by institutional support networks and structural impediments in input delivery systems [32].

Table 6
Estimation of dual cost Cobb-Douglas Frontier cost function

Variable	Coefficient	Std. Err.	P > z	[95% Conf.Interval]
Output (lnoutput)	0.8739272***	0.0181355	0.000	.8383823.909472
Land Price (lnpland_norm)	0.2695582***	0.0955612	0.005	.0822616.4568548
Labor Price (lnplab_norm)	0.146683*	0.0850346	0.085	− .0199817.3133476
Oxen Price (lnpoxe_norm)	0.1452494*	0.0818973	0.076	− .0152664.3057652
Fertilizer Price (lnpfer_norm)	0.1529312	0.0978798	0.118	− .0389096.344772
Seed Price (lnpsee_norm)	0.1762822**	0.0883069	0.046	.0032038.3493607
Constant	0.1507713	0.43524	0.729	− .70228331.003826
ln(σ_v^2)	-4.391939***	0.3049951	0.000	-4.989718-3.794159
ln(σu^2)	-1.976088***	0.1368969	0.000	-2.244401-1.707775
σ_v	0.1112507	0.0169655		.0825081.150006
σ_u	0.3723042	0.0254837		.3255626.4257566
σ^2	0.1509871	0.0167174		.1182216.1837527
λ $(\raisebox{1ex}{\$}\sigma_u\$/\raisebox{-1ex}{\$}\sigma_v\$)$	3.346535	0.0388547		3.2703813.422689
LR test of σ_u=0: chibar2(01) = 43.34			Prob > = chibar2 = 0.000	
Number of observations = 360			Wald chi2(6) = 2433.98	
Log likelihood = 5.8532316			Prob > chi2 = 0.0000	
*, ** and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively				
Source: Model output 2025				

According to the empirical diagnostics, the computed dual cost frontier model offers a remarkably strong fit for the data. The Wald chi2(6) statistic of 2433.98 ($p < 0.001$) shows the independent variables are jointly highly significant in explaining total production costs. Crucially, the Likelihood Ratio test (chi2 = 43.34, $p < 0.001$) strongly rejects the null hypothesis of zero cost inefficiency, confirming that a conventional OLS model is inadequate and the SFA framework is statistically required. The lambda parameter (λ = 3.35), which shows that volatility from cost inefficiency (σ_u) significantly outweighs variance from random idiosyncratic shocks (σ_v), supports this. This indicates that achievable management and allocative inefficiencies, rather than uncontrolled external causes, are the main cause of smallholders' excess costs.

The computed coefficients show direct cost elasticity in relation to output and normalized input prices because the variables are defined in a log-log framework. Positive parameters in a dual cost frontier, in contrast to a production frontier, show elements that rise overall spending. A 1% increase in agricultural output results in an approximate 0.87% rise in overall production costs, according to the estimated cost elasticity of output of 0.874. This divergence suggests that while physical production faces minor diminishing returns, larger-scale operations successfully dilute fixed transaction and input procurement costs, yielding structural economies of scale. The existence of economies of scale among the farms investigated is mathematically confirmed by the fact that this value is strictly smaller than unity. In line with recent dual-cost and meta-frontier research in smallholder agricultural systems, this indicates that smallholders can reduce their average per-unit production costs by growing their current operational scale [33], [34].

Normalized land rental and purchase costs have the biggest and most statistically significant influence on farm expenditures when it comes to input price drivers. The main structural cost pressures these households face are land access and rising tenure costs, as evidenced by the 0.27% rise in total production costs that results from a 1% increase in the normalized land price. This significant flexibility is in line with recent empirical studies that show considerable plot fragmentation, acute land scarcity, and intense tenure strain in developing agrarian settings[25]. The overall cost frontier rises sharply when land values rise due to population pressures, putting farmers under more stringent resource and financial limitations.

Commercial seed prices also show up as a very important factor influencing overall farm expenses. According to the model, a 1% increase in seed price results in a 0.18% increase in overall expenses, indicating a significant reliance on purchased, market-driven seed outlays. According to recent studies examining financial limitations and input utilization in smallholder systems, this substantial expenditure pressure reflects regional realities where cash-strapped smallholders confront severe structural liquidity constraints during planting cycles [35]. Technical and financial inefficiencies may worsen if households with limited resources are forced to go back to low-quality recycled seeds due to rising commercial seed costs.

Finally, pay for physical labor and the cost of renting oxen are statistically significant at the 10% level, raising overall expenses by about 0.15% for every 1% increase in price. This reveals a significant susceptibility to seasonal factor market limitations during cycles of labor-intensive harvesting and plowing [36].

3.2.3 Efficiency Score

Table 7
Summary Technical, Allocative and Economic efficiencies of Teff Production

Efficiency	Mean	Std. Deviation	Minimum	Maximum
Technical Efficiency	0.8245168	0.1188989	0.3366151	0.9686542
Allocative Efficiency	0.7563403	0.1366328	0.2763186	0.9611906
Economic Efficiency	0.6378977	0.1800231	0.093013	0.9291261
Source: own computation 2025				

According to the summary data, the sample households have an overall economic efficiency of 63.79%, an allocative efficiency of 75.63%, and a mean technical efficiency of almost 82.45%. This suggests that although manufacturers can maximize production from the resources they have, they have more difficulty optimizing input

combinations to minimize costs based on current market pricing. Significant performance gaps throughout the sample are highlighted by the large differences between the minimum and maximum scores, especially in economic efficiency, which falls as low as 9.30%. By addressing resource misallocation, households could achieve the frontier level of economic efficiency without sacrificing their current output levels by reducing their production costs and input usage by approximately 36.21%, according to the average results (Table 7).

Source: own computation 2025

The efficiency decline among the sample households is evident in the multi-panel visualization in the above picture. The distribution of technical efficiency in the left panel is strongly biased to the right, closely clustering between 0.80 and 1.00. With significant density peaks close to the production frontier (0.90 to 0.97), this suggests that the majority of producers are quite skilled at using physical inputs. On the other hand, the middle panel's allocative efficiency distribution moves away from the frontier, becoming more symmetrical and centering lower with noticeable peaks between 0.70 and 0.80. This change shows that choosing the best input mix based on market prices is far more difficult than technical management, maybe because of credit limitations or flaws in the market. As a result, the economic efficiency distribution in the right panel shows a compounding effect; it is much larger, flatter, and moved to the left, with a lower tail that extends to 0.10 and a broad peak between 0.50 and 0.75. This wide dispersion supports systemic performance inequity by graphically illustrating how widespread allocative failures, rather just technical flaws, significantly impair overall economic and financial viability (Fig. 2).

3.2.4 Determinants of economic inefficiency

Table 8
Determinants of Technical, Allocative and Economic Inefficiencies

Inefficiency Variables	Technical Efficiency		Allocative Efficiency		Economic Efficiency	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
Educational Level	-0.5372***	0.1813	-0.5784***	0.2078	-0.0735***	0.0184
Gender	-0.3789	0.2824	-0.3115	0.2895	-0.0371	0.0249
Farm Experience (Years)	-0.0236***	0.0060	-0.0277***	0.0066	-0.0029***	0.0007
Livestock Holding (TLU)	-0.0945***	0.0235	-0.0851***	0.0247	-0.0091***	0.0023
Extension Service	-1.1818***	0.2061	-1.1899***	0.2184	-0.1490***	0.0203
Market Information	0.1916	0.1770	0.0943	0.1838	0.0111	0.0182
Access to Training	-0.4002**	0.1739	-0.4088**	0.1864	-0.0463**	0.0182
Access to Credit	-0.4755***	0.1772	-0.4118**	0.2063	-0.0407	0.0184
Cooperative Member	0.0422	0.1776	0.0380	0.1870	0.0066	0.0180
Weather Condition	-0.5374***	0.2051	-0.4927**	0.2220	-0.0526**	0.0217
Constant	0.7155	0.4706	1.0197**	0.4666	0.6455***	0.0455
*, ** and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively						
Source: Model output 2025						

The directional impact on structural efficiency in a stochastic frontier framework modeling the determinants of inefficiency is determined by the algebraic sign of the estimated coefficients; that is, a negative coefficient indicates that the variable reduces inefficiency, moving the farm closer to the production or cost frontier (increasing efficiency), whereas a positive coefficient indicates a factor that increase structural waste or allocative distortions. According to the joint estimator, the main determinants of technical, allocative, and economic performance among the sampled smallholders are human capital components, institutional connections, resource endowments, and environmental conditions.

The most effective institutional drivers of efficiency gains across all three parameters are contacts with agricultural extension and access to formal training. The large, negative, and highly significant coefficients highlight the simultaneous mitigation of pricing distortions and operational errors by targeted capacity-building workshops and public advisory networks. Extension agents directly support the adoption of best practices like accurate row-planting, timely weeding, and ideal input combinations that simultaneously move smallholders toward the production frontier and down the cost curve by offering real-time agronomic advice and market insights. This finding strongly aligns with the empirical conclusions of [37]and formalizes the argument by recent agricultural efficiency researchers [38] that localized institutional knowledge transfers are pivotal for optimizing technical practices and minimizing input cost inflation in smallholder agrarian ecosystems.

In order to reduce agricultural inefficiencies, human capital more especially, formal education and accumulated farming experience is essential. Because literate and highly educated smallholders have the superior cognitive capacity needed to understand commercial input labels, apply sophisticated crop-protection strategies, and negotiate volatile market pricing, higher educational attainment significantly reduces technical, allocative, and economic inefficiencies. Simultaneously, accumulated farming experience reduces these inefficiencies even further by promoting localized, implicit knowledge about seasonal weather patterns and best techniques for managing soil. These findings collectively provide compelling evidence for the human capital theory applied to agrarian efficiency by recent researchers like [39], supporting the idea that formal education and real-world production experience work in concert to reduce expensive management delays and market search frictions.

The Tropical Livestock Unit (TLU) inventory, which measures asset accumulation, is a crucial tool for easing smallholder farmers' resource and draft power constraints. A functional source of non-human capital and an important proxy for household wealth, increased cattle ownership significantly reduces technical, allocative, and economic inefficiencies. Richer farmers use draft animals to prepare fields on time and obtain organic manure to supplement chemical inputs, which stabilizes production costs and maximizes allocative efficiency. In contemporary sub-Saharan empirical literature[40], [41], livestock holdings serve as an internal insurance buffer against unexpected liquidity shocks, enabling households to self-finance and buy commercial inputs at the best times instead of giving in to crucial management and production delays.

One of the main institutional mechanisms for overcoming seasonal input liquidity frictions is access to agricultural microcredit. Formal borrowing options efficiently alleviate the severe capital constraints that often cause seasonal cash famine between planting and harvesting periods by minimizing both technical and allocative inefficiencies. Credit availability helps smallholders avoid compromising on less productive, sub-optimal choices because of cash limitations by mitigating these liquidity gaps and enabling them to purchase high-yielding crop varieties and optimal chemical inputs during crucial operational periods. The credit-constrained efficiency frameworks proposed in recent global agricultural finance literature [42], [43] are strongly aligned with this

behavioral pattern, indicating that the availability of institutional credit stabilizes the allocative frontier by coordinating household purchasing power with critical seasonal agricultural milestones.

To safeguard the production frontier from disturbances brought on by climate change, environmental stability and farm-level climate adaption techniques are essential. Technical, allocative, and economic inefficiencies are strongly negatively correlated with favorable weather conditions, demonstrating how unfavorable climate events consistently lower the deterministic frontier and cause significant operational instability. This structural connection emphasizes that maintaining both high output technical efficiency and microeconomic cost targets depends on developing localized climate resilience, such as by investing in small-scale irrigation infrastructure or using moisture-stress-tolerant seed varieties. These results firmly corroborate recent regional research on the effects of Climate-Smart Agriculture (CSA) conducted by [44] and [45], demonstrating that reducing environmental risks is a necessary condition for maintaining agricultural productivity and stabilizing smallholder efficiency.

4. Conclusion and Recommendation

This study investigated the economic efficiency of teff productivity among smallholder farmers in Awabel District, Ethiopia. The study separated random environmental influences from internal management and allocative inefficiencies using primary data and a Stochastic Frontier Analysis framework. This approach is validated above standard least squares by the diagnostic tests, which show that controllable institutional and operational deficiencies, not pests or climate shocks, are the cause of production shortfalls and cost increases. The descriptive analysis reveals a severely limited agrarian system divided by a growing economic gap between resource-poor, subsistence-constrained households and well-capitalized, commercially focused producers. Extreme differences in localized crop yields and total household expenditures are caused by the fact that more than half of the farmers assessed have no access to formal agricultural training or microcredit facilities. By identifying actionable management gains, these findings directly support SDG 1 (No Poverty) and SDG 2 (Zero Hunger) through improved smallholder yields and income security. Furthermore, optimizing input utilization advances SDG 12 (Responsible Consumption and Production) by fostering resource-efficient, sustainable agrarian systems in rural Ethiopia.

According to the empirical estimation of the production function within a land-fragmented economy, teff farming operates under declining returns to scale. The size of cultivated land is the main factor driving physical output growth, and yields are positively and statistically significantly impacted by oxen traction, chemical fertilizers, modern pesticides, and traditional labor. On the other hand, due to a systemic institutional bottleneck where farmers rely on subpar recycled seeds and lack sufficient extension advice, improved seed technology is still statistically negligible. The most significant rising pressure on expenditures on the cost side comes from normalized land rental costs, which are followed by oxen rentals, labor wages, and seed prices. Despite obvious evidence of physical economies of scale, intense local rental competition significantly raises operating expenses and effectively erodes profit margins.

Although smallholder households have the highest relative proficiency in technical efficiency, their performance in allocative and economic efficiency is negatively impacted by significant market frictions. This shows that although companies effectively manage physical inputs, they find it difficult to optimize input combinations to reduce costs due to fluctuating market pricing. Visual distributions indicate allocative and economic measures flattening down and skewing significantly to the left, indicating that systemic allocative failures rather than purely technological flaws are the main cause of this growing economic divide. The joint estimation of inefficiency

determinants shows that the main structural drivers of success are human capital components, institutional connections, livestock endowments, and environmental stability; extension contacts, formal training, and microcredit serve as the essential mechanisms to address seasonal cash constraints.

Based on the empirical insights, the following focused policy actions are designed to align the particular duties of community actors, governmental authorities, and research institutions:

Local policymakers must actively encourage the creation of agricultural asset-sharing cooperatives in order to take advantage of established economies of scale and protect households from erratic seasonal factor market fluctuations. Asset-poor households can obtain necessary manual labor buffers by setting up community-owned shared mechanization services, such as automated row-planters and post-harvest threshers. By protecting low-income smallholders from excessive market rates for physical labor and oxen rentals, this collective structural intervention will significantly reduce their average production costs per unit. In order to lessen seasonal cash famine and the systemic allocative inefficiencies and cost distortions that arise between planting and harvesting cycles, resource-poor farmers must actively participate in these community-governed networks.

Local governments must create an open, community-run land rental register since land size is the main factor influencing output and land rental prices are the single most inflationary pressure on production costs because of plot fragmentation. Resource-poor farmers will be protected from speculative price gouging, production costs will be stabilized, and smallholders will have the tenure security necessary to undertake long-term investments if long-term lease arrangements are standardized and institutionalized at the regional level. Furthermore, the emphasis of public extension services must change from merely promoting the adoption of basic inputs to offering comprehensive management training, as controllable internal inefficiencies outweigh random environmental shocks. To improve the structural cognitive capacity of resource-poor farmers, government advisory offices should combine functional adult literacy programs with field-level agricultural workshops. At the same time, they should increase access to rural microfinance institutions and agricultural cooperatives in order to introduce flexible, low-interest production loans that are specifically designed for the teff crop cycle.

Regional research institutes, universities, and development NGOs must establish strategic partnerships to completely transform the local seed distribution network because improved seeds currently fail to significantly increase productivity due to widespread grain recycling and sub-optimal management. In order to shift smallholders from low-quality recycled grains to certified, high-yielding teff types, these organizations must take the initiative. Importantly, thorough field training centered on matching particular agro-ecological zones with appropriate genetic seed features must be combined with input delivery networks created by NGOs and academic partners. In order to reduce wasteful spending on uncertified, underperforming market varieties that now raise smallholders' overall operating costs, this focused information transfer from researchers and institutions is essential.

Declarations

Conflict of interest

Consequently, all the sources of the materials used in this research have been recognized. There are no conflicts of interest.

Ethics Approval

The Research Ethics Committee at Debre Markos University's Research and Technology Transfer Directorate in Ethiopia waived ethical approval. Because the study only used voluntary questionnaire surveys and did not include biological sampling, clinical procedures, or vulnerable populations, the exemption was approved.

Accordance with Ethical Standards

This study adhered to accepted criteria for research involving human subjects as well as Debre Markos University's institutional ethical requirements. The study was conducted with rigorous adherence to important ethical principles, such as informed consent, voluntary participation, and respondent confidentiality and anonymity.

Informed Consent

Before any data was collected, informed consent was acquired from each individual participant in the study.

Consent to Publish

Not applicable.

SDG Alignment

This study uses stochastic frontier analysis to assess the efficiency of teff production among smallholder farmers in Ethiopia's Awabel District. The findings demonstrate that internal operational and institutional deficiencies, not climate shocks, are the primary cause of yield shortages and increased costs. There are significant income and production disparities since more than half of the farmers in the sample lack microcredit and extension training. Thru improved smallholder yields and livelihoods, our findings directly advance SDGs 1 (No Poverty) and 2 (Zero Hunger) by identifying actionable management advantages. Additionally, by promoting sustainable, resource-efficient agricultural systems, enhancing input efficiency contributes to SDG 12 (Responsible Consumption and Production).

Clinical trial number

not applicable. There are no patient studies, human clinical trial interventions, or experimental medical techniques used in this work.

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Author Contribution

Belete Animaw came up with the idea for the study, created the technique, and wrote the first draft of the manuscript. Data collection, statistical analysis, and interpretation were carried out by Haymanot Bassie and Bantayehu Tamrie. In addition to managing project administration, Silabat Enyew and Gebyaw Demeke carried out the literature review and improved the discussion part. Each author (BA, HB, BT, SE, and GD) read the final drafts, approved the version submitted for publication, and made a substantial contribution to the critical revision of the intellectual content. As the corresponding author, BA guarantees the study's overall integrity.

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Data Availability

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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Figures

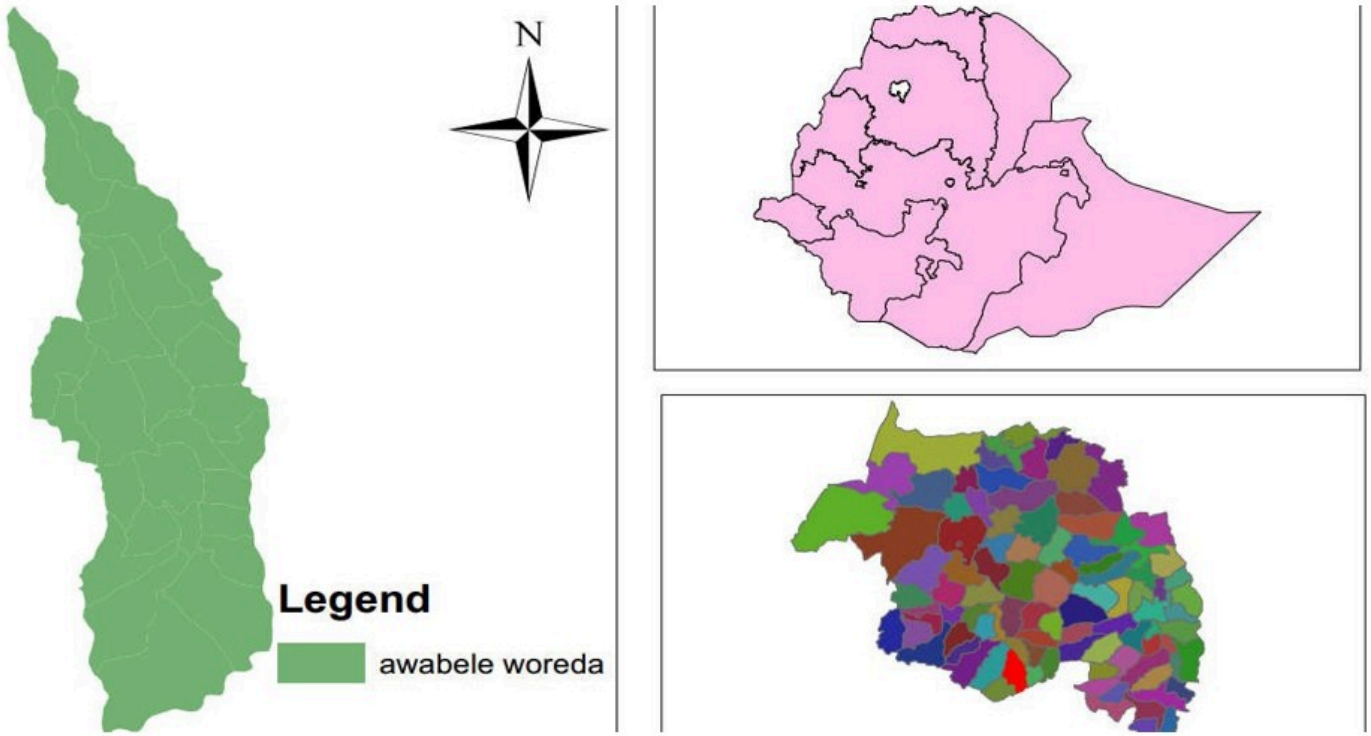


Figure 1

Geographical location of the study area

Source: A geographic information system (GIS), 2025.

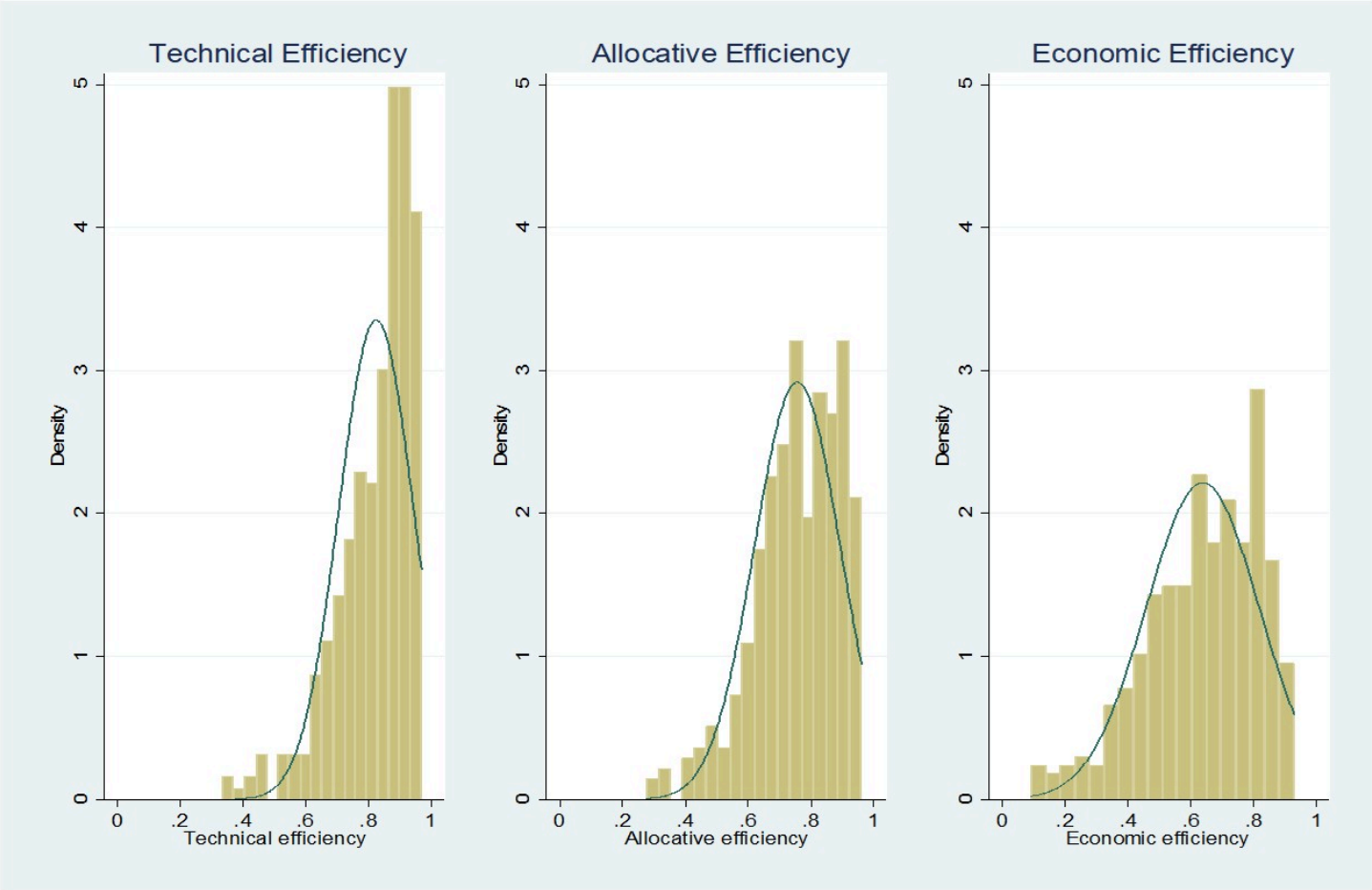


Figure 2

Distribution of Technical, Allocative and Economic Efficiency scores

Source: own computation 2025