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Efficiency estimation and determinants in small-scale dairy production in Eritrea

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ABSTRACT

The Eritrea dairy sector provides livelihood for over 70% of the population. However, this sector is still at its subsistence level. Therefore, improving the sector requires that farm-level efficiency is determined for sustainability. Anseba, Debub and Maekel areas in Eritrea were selected for the study. Deterministic and stochastic frontier methods were used to determine technical (T), allocative (A) and profit/economic (E) efficiencies (E) of small-scale dairy farmers. Results show that feed, concentrates, labour and herd size were important inputs required for technical Efficiency (TE). Adding medication/vaccination to these inputs increased EE of small-scale dairy farmers. TE and AE level of Eritrea, Anseba, Debub and Maekel were low, ranging from 31.57% - 40.65%, and 12.23 - 38.00% respectively. However, the EE was above 50%, (71.17%) Anseba and Maekel (93.39%) for except in Debub (32.24%). While years of dairy experience, cooperative membership, use of agricultural extension service and native of Maekel reduced technical inefficiencies, number of household female members and milking cow twice daily increased technical inefficiencies. Also, age and educational level of farmer, size of land mapped out for food production, extensive method of dairy farming and native of Debub increased economic inefficiencies. Based on findings, interventions/projects should target increasing herd size of farmers and expanding agricultural advisory service to provide innovative and market information to small-scale dairy farmers. Policies aimed at increasing land size allocated for animal feed and concentrates should be enacted and farmers should be encouraged to join/form cooperatives for easy access to dairy inputs and strong bargaining power.
Key words: Diary Production, Eritrea, technical efficiency

RÉSUMÉ

Le secteur laitier en Érythrée fait vivre plus de 70 % de la population. Cependant, ce secteur demeure à un stade de subsistance. Son amélioration passe par l'évaluation de l'efficacité des exploitations laitières au niveau des fermes pour assurer la durabilité. Les régions d'Anseba, de Debub et de Maekel en Érythrée ont été retenues pour cette étude. Des méthodes de frontière déterministe et stochastique ont servi à déterminer l'efficacité technique (ET), l'efficacité allocative (EA) et l'efficacité

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économique (EE) des petits éleveurs laitiers. Les résultats indiquent que la quantité d'aliments, de concentrés, la main-d'œuvre et la taille du troupeau constituent les facteurs principaux intervenant dans l'ET. L'addition de soins vétérinaires (médicaments/vaccination) à ces facteurs a accru l'EE des exploitations laitières à petite échelle. Les valeurs d'ET et d'EA observées pour l'Érythrée ainsi que pour Anseba, Debub et Maekel restent modestes (de 31,57 % à 40,65 % pour l'ET et de 12,23 % à 38,00 % pour l'EA). Toutefois, l'EE dépasse 50 % pour Anseba (71,17 %) et Maekel (93,39 %), à l'exception de la région de Debub (32,24 %). L'ancienneté dans l'activité laitière, l'appartenance à une coopérative, l'usage des services de vulgarisation agricole et le fait d'être originaire de Maekel réduisent les inefficiences techniques. En revanche, le nombre de femmes dans le ménage et la traite biquotidienne augmentent ces inefficiences. Par ailleurs, l'âge et le niveau d'éducation de l'éleveur, l'ampleur des terres consacrées à la production de denrées alimentaires, les pratiques d'élevage extensif et l'origine de Debub accroissent les inefficiences économiques. Au vu de ces résultats, il est préconisé d'encourager l'accroissement de la taille des troupeaux et l'expansion des services de conseil agricole pour diffuser des innovations et des informations sur les marchés. Les politiques devraient soutenir l'augmentation des superficies cultivées en fourrages et concentrés et promouvoir la formation de coopératives (ou l'adhésion aux coopératives) afin de faciliter l'accès aux intrants laitiers et d'améliorer le pouvoir de négociation des petits éleveurs.

Mots-clés : production laitière, Érythrée, efficacité technique

INTRODUCTION

Like in other sub-Sahara African countries, agriculture is the key pivot of the Eritreans economy, employing about 75% of the populace (VEDAMAN, 2015). The dairy sector is very important to the Eritrean agriculture though still at subsistence level. It is one of the major sources of livelihood and insurance among small-scale farmers and also acts as a coping strategy during drought and other disasters (IFAD, 2009). The sector suffers from underdeveloped value chain in terms of poor supply of input, market access, and processing plants (Teagasc, 2017). However, the sector is a good source of biogas, draught power, organic fertilizer and means of transportation especially for farmers with no access roads (IFAD, 2009).

More than 50% of the total milk produced in Eritrea is sold locally with about 20,000 litres processed by five processing plants daily (Teagasc, 2017). Milk production varies depending on the production systems, namely: extensive with local cattle breeds, intensive with exotic breeds and intensive with local breeds. Intensive production with exotic breeds' yields about three times of milk compared to the other systems (VEDAMAN, 2015). Several project interventions have been put in place to develop the Eritrean dairy sector for increased production and productivity through the supply of improved Holstein and Halfa breeds, vitamins and minerals, animal drugs, laboratory equipment, energy, among others (IFAD, 2009; MASE, 2013; RU, 2017; Teagasc, 2017).

The expected output of these interventions may be jeopardised if a proper in-depth understanding of the Eritrea dairy sector is not done. One thing is to provide the small-scale dairy farmers with the desired inputs, but on the other hand, it is essential that farmers are well equipped to efficiently utilise the supplied input for increased dairy production and productivity, amounting to improved livelihood and a developed economy. It is important to ensure that technologies disseminated to small-scale farmers are cost-effective and in turn, farmers resourcefully allocate their scarce resources to achieve increased dairy output in the short-run through increased profit for increased income (Bravo Ureta and Pinheiro, 1997; Dorfman, 2022). However, there is a paucity of literature highlighting this very important evaluation of the dairy sector in Eritrea, except for Ghebremari (2004) and Hoda and Siddiqui (2016), whose studies on dairy production function focused at sub-regional level. Conversely, the efficiency level of small-scale dairy farmers has been studied extensively in other East African countries such as Kenya (Nganga *et al*., 2010; Maina, 2018), Tanzania (Mbehoma and Mutasa, 2013) and in Ethiopia (Adane *et al*., 2016; Girma, 2019). Thus, this study focused on evaluating the empirical measures of the farm efficiency level of dairy farmers considering the technical (TE), Allocative (AE) and profit/economics efficiencies (EE) in Eritrea.

There are different approaches developed to estimate efficiencies by different authors such as: Winsten (1957), Zellner and Revankar (1969), Christensen *et al*. (1971), Aigner *et al*. (1977), Meeusen and van den Broeck (1977), Greene (1980), Kumbhakar (1987), Battese (1991), O'Donnell *et al.* (2008) and Kumbhakar *et al.* (2015). Out of all the approaches developed, the deterministic and stochastic frontiers were adopted to analyse the farm efficiencies of small-scale dairy farmers in Eritrea. Although, the deterministic frontier has long been used by some authors for example Bravo-Ureta (1986), Kumbhakar *et al*. (1989) Ali and Chaudhry (1990) and Yarahmadi *et al*. (2021) decades ago for empirical analysis of frontier efficiencies, it was adopted in this study because of it is simplicity, assumptions of deterministic frontier function and randomness that depends on variations in the inefficiency. Stochastic frontier analysis was also used to validate the former. It has been used by Nganga *et al*. (2010), Yilmaz *et al*. (2020), Chandel *et al*. (2022) and Sultana *et al*. (2023), among others.

METHODOLOGY

A total of 422 dairy farmers were randomly selected from three regions and several sub-regions as shown in Table 1. Four, nine and eight sub-regions were selected from Anseba, Debub and Maekel respectively. Information was elicited from the selected farmers using a structured questionnaire. Information sought included farmers' demographics and factors of production, among others. A total of, 379 dairy farmers were used for the study as 13, 29 and one farmer(s) were dropped respectively from Anseba, Debub and Maekel due to incomplete data on factors of production.

Table 1. Distribution of the study area

REGIONS	Anseba			Debub			Maekel		
	Sub-region	**Freq**	**Percent**	**Sub-region**	**Freq**	**Percent**	**Sub-region**	**Freq**	**Percent**
	Elabered	26	21.67	Dbarwa	33	27.50	Akria	8	6.67
	Hagaz	25	20.83	Dekemhare	21	17.50	Asmara	1	0.83
	Hamelmalo	26	21.67	Emini-Haili	5	4.17	Berik	39	32.50
	Keren	43	35.83	Mendefera	48	40.00	Gala Nefhi	37	30.83
				Segeneity	11	9.17	Serejeka	39	32.50
				Senafe	11	9.17	Tsetserat	10	8.33
				Adikeih	10	8.33	Peradizo	16	13.33
				Adilogo	1	0.83	Mai Temenay	2	1.67
				Adiquala	10				
	Total	**120**	**100**		**150**	**100**		**152**	**100**

Source: Field survey, 2022

Theoretical and analytical framework. Several frontier models have evolved since the productive efficiency measures of Farrell in 1957 (Chiona *et al*., 2014). There are three major models that are used in predicting production frontier, namely: deterministic frontiers, stochastic frontiers and panel data (Battese, 1991).

For this study, the deterministic frontier model was adopted from (Battese, 1991) and as specified in Kumbhakar *et al*. (2015):

$$\ln y_i = lny_i^* - u_i, \quad 1 \geq u_i \geq 0 \qquad (1)$$

$$lny_i^* = f(x_i;\, \beta) \quad i = 1, 2, \ldots, N \qquad (2)$$

Where Y_i is the likely production output for ith farm, $f(x_i;\, \beta)$ is a fitting function, like Cobb-Douglas or Translog, of the vector,x_i, of ith farmer inputs and β is a vector of the corresponding vector; U_i is a non-negative random variable that specifies factors that contributes to non-attainment of maximum production efficiency of the ith farmer, while *N* is the number of farms. The u_i in eqn 1 explains the technical inefficiency of the ith farmer with values ranging from zero to one, implying that y_i is restricted by the non-stochastic (deterministic) frontier output, $f(x_i;\, \beta)$,

$$TE_i = \frac{Y_i}{Y_i^*} = f(x_i;\, \beta)\, exp\frac{-U_i}{f(x_i;\, \beta)} = \exp(-U_i)$$
(3)

Eqn 3 can be estimated with maximum likelihood estimator (MLE) (Battese, 1991) or corrected ordinary least square (COLS) estimator proposed by Winsten (Winsten, (1957) Battese, 1991 and Kumbhakar *et al*., 2015, or corrected mean absolute deviation (CMAD), which is an alternative to OLS that uses mean or medium absolute deviation (MAD) estimator (Kumbhakar *et al*, 2015). Thus, the predicted $\widehat{TE}_i$ can be obtained for the ith farmer as follows:

$$\widehat{TE}_i = \frac{y_i}{f(x_i;\, \hat{\beta})} \qquad (4)$$

Where $\hat{\beta}$ is either maximum-likelihood or COLS or CMAD estimator for $\hat{\beta}$.

Stochastic production frontier model with output-oriented inefficiency as specified by Aigner *et al* (1977) and Meeusen and van den Broeck (1977) was used to analyse the technical, allocative and economic efficiency of dairy farmers in Eritrea; and is specified thus:

$$\ln y_i = lny_i^* - u_i, \qquad u_i \geq 0$$
(5)

$$lny_i^* = f(x_i;\, \beta) + v_i - u_i \quad i = 1, 2, \ldots, N$$
(6)

Where v_i is the random error with a zero mean that is associated with random factors that cannot be controlled by the dairy farmer and u_i measures the ith technical inefficiency i.e. the observed output, *y*, less its frontier output $[g(u_i\, \beta) + v]$, which is a half normal distribution i.e. more than zero. The residuals obtained could be considered as estimates of the ith error term (Jondrow *et al*., 1982). The Cobb–Douglas production function is specified as:

$$\ln Y_i = \beta_0 + \sum_{i=0}^{n} \beta_i \ln X_i + v_i - u_i\,, i = 1, 2, \ldots, 379\ dairy\ farmers \qquad (7)$$

Where Y_i = quantity of milk in litres per ith farm, X_1 = labour in hours/year, X_2 = feed in Nakfa, X_3 = medication/vaccination in Nakfa, X_4 = concentrates in Nakfa, X_5 = other costs (costs of water, artificial insemination, transportation, maintenance and energy such as fuel and electricity) X_6 = herds size in number and X_7 = size of farm land in acre; $v_i - u_i$ = error terms, ln = natural logarithm; β_0 = model intercept, and β_i = equation parameters.

The output elasticity with respect to input X_i is constant for every observation though differs across X_i and is derived by:

$$\varepsilon_i = \frac{\partial lny}{\partial lnx_i} = \beta_i \qquad (8)$$

Hence, the returns to scale (RTS) are obtained as:

$$RTS = \sum_{i=1}^{i} \varepsilon_i = \sum_i \beta_i = r \qquad (9)$$

Maximum likelihood estimation (MLE) was used to estimate the SFA (Greene, 1980) in order to select the parameter estimates $(\beta, \sigma_\varepsilon^2)$ that boost the likelihood of getting the data:

$$lnL = \frac{n}{2\ln[^{\omega}/_{2}]} - {}^{n}/_{2ln\sigma^2} + \sum_i^n \ln[1 - P(\varepsilon_i\sqrt{\gamma}/\sigma)\sqrt{1-\gamma}] - {}^{1}/_{2\sigma^2}\sum_{i=1}^n \varepsilon_i^2$$
(10)

Where σ_v^2 and σ_u^2 are the variances for the error terms, added, $\sigma_\varepsilon^2 = \sigma_u^2 + \sigma_v^2$ and $\gamma = {}^{\sigma_u^2}/_{\sigma_\varepsilon^2}$. The MLEs of $\beta,\ \gamma, and\ \sigma_\varepsilon^2$ were achieved using the adjusted first-order partial derivatives where the probability function rate was highest equating $\beta,\ \gamma, and\ \sigma_\varepsilon^2$ to zero while resolving the non-linear equations (Greene, 1980).

Furthermore, profit/economic efficiency (EE) of ith dairy farm was derived analytically from eqn (7) by normalizing the observed input vectors, X_i with price of milk per litre. The stochastic profit function is expressed as:

$$\pi_i^* = \frac{\pi_i}{P} = h(X_i, z)\exp(v_i - u_i) \quad (11)$$

$$\pi_i^* = \frac{\pi_i}{P} = h(X_i, z)\exp(\varepsilon_i) \quad (12)$$

Where π_i^*= normalized profit of ith farmer, $\frac{\pi_i}{P}$ = expression of the normalized profit, z = vector of fixed input, p = price of milk used to normalize the variables in eqn (7), π_i= observed profit of ith farmer derived by total revenue less total production cost and exp (ε_i) = composite error term.

To obtain Profit efficiency of ith farmer,

$$\text{EE} = \frac{\pi_i}{\pi_i^*} = \frac{(X_i, z)\exp(\varepsilon_i)}{(X_i, z)\exp(v_i)} \quad (13)$$

$$\text{EE} = \frac{\exp(\varepsilon_i)}{\exp(v_i)} = \exp(-u_i) \quad (14)$$

Specifically, the Cobb–Douglas production function was used and specified as:

$$\ln \pi_i^* = \beta_0 + \sum_{ik=0}^n \beta_{ik} \ln X_{ik} + \varepsilon_i, i = 1, 2, \ldots, 379\ dairy\ farmers \quad (15)$$

Where π_i^* = normalized profit of ith farm, X_1 = normalized labour in hours/year, X_2 = normalized feed in Nakfa, X_3 = normalized medication/vaccination in Nakfa, X_4 = normalized concentrates in Nakfa, X_5 = normalized other costs, X_6 = normalized herds size in number and X_7 = normalized size of farm land in acre.

The choice of profit maximization in place of cost minimization was to ascertain the AE of the ith dairy farmer. Based on farmer's production decisions, profit maximization assumes that Y_i and X_i is endogenous (Kumbhakar *et al*., 2015). Therefore, the AE was calculated as the ratio of TE and EE.

Technical and profit/economic inefficiency function specification. The determinants of the technical and profit inefficiencies of dairy farmers were modelled as follows:

$$u_i = \delta_0 + \sum_{i=1}^9 \delta_i z_i + \mu \quad (16)$$

Where: u_i = Technical efficiency of ith farmer, $\delta_0\ and\ \delta_i$ = parameters to be estimated, z_1 = age of ith farmer in years, z_2 = sex of ith farmer (male = 1 otherwise 0), z_3 = educational level of ith farmer in number (1= No education, 2=Elementary school (5 years), 3=Junior to High School (up to 6-11 years), 4=Vocational School, 5=University education), z_4 = dairy experience of ith farmer in years, z_5 = household size of ith farmer in number, z_6 = cooperative membership of ith farmer (yes = 1 other 0), z_7 = number of females in ith farmer household in numbers, z_8 = milking cow twice a day by ith farmer (yes = 1 otherwise 0), z_9 = ith farmer household use agricultural advise service (yes = 1 otherwise 0). Other z_i used in addition for profit inefficiency were: z_{10} = ith farmer experiencing a shortage of water within a year (yes = 1 otherwise 0), z_{11} = size of land mapped out for food production by ith farmer in acre, z_{12} = distance to the closest dairy farm in kilometers, z_{13} = method of dairy farming by ith farmer (intensive (yes = 1 other 0), semi-intensive (yes = 1 other 0), extensive (yes = 1 other 0), z_{14} = region (Anseba (yes = 1 otherwise 0), Debub (yes = 1 other 0), Maekel (yes = 1 other 0).

Test statistics. To verify the deterministic and stochastic model specifications, Skewness/Kurtosis tests for Normality test proposed by Schmidt and Lin (1984) was carried out before estimating the maximum likelihood. Skewness test as specified below:

$$\sqrt{b_i} = \frac{j_3}{j_2\sqrt{j_2}} \quad (17)$$

and $j_2 = \sum(x-\overline{x})^2/n$ while $j_3 = \sum(x-\overline{x})^3/n$

Where j_2 and j_3 are the 2nd and 3rd OLS sample residuals respectively, $(x-\overline{x})^2$ is the 2nd moment of x, $\sum(x-\overline{x})^3/n$ is the 3rd moment of x.

For more validation of the stochastic model estimation, log-likelihood (LR) test was carried out as the Skewness/Kurtosis tests does not utilize the information from the distribution functions of the u_i. While the test is taken before the MLE, LR test is done after the MLE and it estimates the specific model precisely (Kumbhakar *et al.*, 2015). The LR test is specified as:

$$LR = -2[ln(H_0) - ln(H_1)] \quad (18)$$

Where $ln(H_0)$ and $ln(H_1)$ are log-likelihood values of the OLS and SFA model respectively.

RESULTS and DISCUSSION

Table 2 shows the socio-economic characteristics of the dairy farmers selected for this study. The mean age of 57.21 shows that farmers were still at the active age. Sex skewed towards one implying that majority of the farmers are men with mean educational level of 2.43 indicating that a majority of the farmers attained elementary school thus depicting a high illiteracy level. The mean years of experience were 16.51 implying that farmers were experienced in dairy production. On average, the household size was 6.89 while the component of female members was 3.19. Almost half (1.09) of the farmers used agricultural advisory services and more than half (1.23) were members of cooperatives. The major dairy production systems was intensive (260), followed by semi-intensive (101) and then extensive (18).

The input variables show the mean of 4470.55, 2163.16, and 3122.99 Nafka, respectively, for medication/vaccination, labour, and other costs (1USS$=Nafka). The mean value of 6.83 for herd size indicates that farmers operated at subsistence level and had average land size of 1.29 acres. The mean values for concentrates and feed show that both inputs contributed more than of double the cost of other inputs.

Stochastic Frontier for technical efficiency. Across the estimators, the coefficients and standard errors of the MLE and CMAD were somehow close compared to the COLS. Again, the signs against the coefficients differed for the labour and other costs, and a number of significant variables varied as well. Using the frontier coefficients, four input variables are positive and significant at 1% and 10%, implying that they are very important inputs in dairy farming. The output elasticity of herd size is above four times larger compared to labour, feed and concentrates. The implication is that 1% increase in labour, feed, concentrates and herd size will increase milk quantity by 19.7%, 13.9%, 4.2% and 80.5%, respectively. For increased milk production, increasing the herd size is of utmost importance indicating the need for dairy production in Eritrea to transition from subsistence farming to commercial dairy production. This finding is in line with Al-Sharafat (2013) and Mbehoma and Mutasa (2013). While increasing the herd size, production/cultivation of feed and concentrates needs to be improved by irrigation to enhance availability among the dairy farmers. This is especially important in a drought-prone countries such as in the case of Eritrea. Again, the labour market requires improvement for availability of labour. These findings correspond with Al-Sharafat (2013), Girma (2019) and Yarahmadi *et al*. (2021).

Table 2. Descriptive summary of farmer's inefficiency and input variables

Variable	N	Mean	Std. Dev.	Min	Max
Age	379	57.21	12.72	24	90
Sex	379	1.16	0.37	1	2
Educational level	379	2.43	0.99	1	5
Years of dairy experience	379	16.51	10.81	1	50
Household size	379	6.89	2.93	1	21
Household female member	379	3.19	1.84	0	12
Use agricultural advise service	379	1.09	0.29	1	2
Cooperative membership	379	1.23	0.42	1	2
Method of dairy farming:	379	1.36	0.57	1	3
Intensive	260	1			
Semi-intensive	101	2			
Extensive	18	3			
Region:					
Anseba	107	1			
Debub	121	2			
Maekel	151	3			
Stochastic frontier variables					
Medication/vaccination	379	4470.55	35819.99	0	490000
Labour	379	2163.16	746.17	900	5040
Other costs	379	3122.99	20468.02	0	360000
Herds size	379	6.83	7.15	1	58
Size of farm land	379	1.29	1.49	0	12
Concentrates	379	8422.32	36885.62	0	575000
Feed	379	86227.53	139615.00	150	786360

Source: Field survey, 2022

The γ parameter is 0.9547 indicating that 95.47% of variations in milk production among the small-scale dairy farmers were resulting from disparities in the technical efficiency. RTS coefficient is 0.757 implying a decreasing return to scale.

Stochastic Frontier for profit/economics efficiency. To ascertain the economics efficiency of dairy farmers and their allocative efficiency, profit maximization was estimated (Tables 3 and 4). This is because of its assumption that allows output and inputs to be endogenous (Kumbhakar *et al*., 2015). The CMAD estimation was omitted because of an insignificant intercept. So, the EE reported in Table 3 shows frontier and COLS estimation findings. Coefficients and standard errors of both estimates differ with varying significant input variables. The normalized inputs, namely: labour, feed, herd size and concentrates were positive and significant at 1%. The implication is that the output elasticity of these inputs was very important in profit maximization among small-scale dairy farmers. This means that 1% increase in labour, feed, medication/vaccination, herd size and concentrates would increase profit by 68%, 26.1%, 10.8%, 34.4% and 6.4%, respectively, among small-scale dairy farmers in Eritrea. Therefore, labour and herd size were the most important input that are required for profitable dairy production, followed by feed and medication/vaccination. This finding is in line with Hoda and Siddiqui (2016) in Eritrea and Maina (2018) in Kenya.

Table 3. Maximum likelihood Estimates of Cobb-Douglas Stochastic Frontier for technical efficiency

Variables	Coef.	Std. Err.	Z-test	Coef.	Std.Err.	T-test	Coef.	Std. Err.	T-test
	Frontier			**COLS**			**CMAD**		
Log of labour	0.197	0.117	1.68*	-0.509	0.251	-2.02**	0.010	0.109	0.09
Log of feed	0.139	0.044	3.17***	0.376	0.0895	4.20***	0.251	0.039	6.46***
Log of Medication	0.015	0.013	1.14	0.0171	0.0276	0.62	0.032	0.012	2.66***
Log of concentrates	0.042	0.015	2.76***	0.0348	0.0256	1.36	0.013	0.011	1.16
Log of Other costs	0.005	0.012	0.38	-0.000672	0.0284	-0.02	-0.001	0.012	-0.1
Log of Herd size	0.805	0.058	13.89***	0.959	0.130	7.36***	0.775	0.057	13.69***
Log of Land size	-0.010	0.057	-0.17	-0.136	0.131	-1.040	-0.143	0.057	-2.51**
Constant	4.780	0.977	4.89***	6.408	2.158	2.970***	4.380	0.937	4.67***
usigmas	4.797								
vsigmas	0.230								
$\sigma^2 = \sigma_u^2 + \sigma_v^2$	5.027								
$\gamma = \sigma_u^2 / \sigma^2$	0.9547								
Log likelihood	-522.624								
Wald chi2(7)	440.41								
R squared				0.310					
Raw sum of deviations							217.613		
Min sum of deviations							150.786		
Pseudo R2							0.307		
Number of obs							379		
Returns to scale	0.757								

Source: Field survey, 2022. Significance levels legend: *, **, * represents 1%, 5% and 10% respectively**

Again, γ parameter for EE is 0.875 indicating that 87.5% of variations in milk production among the small-scale dairy farmers were resulting from disparities in the technical efficiency. RTS coefficient is 1.6 implying an increasing return to scale.

Estimation of test statistics. Table 5 shows the skewness test value of -2.686 shows a one-sided hypothesis, therefore the Kodde and Palm critical values was used to test the LR. The LR test critical value at 1% is 24.049 and it's less than the calculated value, 119.9432, implying a rejection of no technical inefficiency. Similarly, the EE skewness test tends to the left with LR test calculated value of 305.3461, significant at 1% of the critical value of 24.049. This implies that inefficiency effects are stochastic.

Levels of technical, Allocative and Economic Efficiency of small-scale dairy farmers in Eritrea. As earlier established, AE was obtained as the ratio of TE and EE. Table 6 shows the farm level efficiencies of small-scale dairy farmers in Eritrea and the selected regions. The mean TE for Eritrea, Anseba, Debub and Maekel were 37.37%, 39.29%, 31.57% and 40.65%, respectively. All the TE was below 50% indicating a relative inefficiency among the small-scale dairy farmers. Farmer's AE was equally very low with mean values of 27.24%, 29.02%, 12.23% and 38.00% respectively for Eritrea, Anseba, Debub and Maekel. The very low AE could explain the relative inefficiency observed in TE, implying that small-scale dairy farmers poorly allocated resources that reduced their TE. However, the EE of the farmers were 67.60%, 71.17%, 32.24% and 93.39% for Eritrea, Anseba, Debub and Maekel respectively. The EE of the farmers were above 50% except for Debub, which was below 50%. Generally, Maekel performed better than other regions in TE, AE and EE.

Table 4. Maximum likelihood Estimates of Cobb-Douglas Stochastic Frontier profit efficiency

Variables	Coef.	Std. Err.	Z-test	Coef.	Std. Err.	T-test
	Frontier			**COLS**		
Log of normalized labour	0.680	0.105	6.49***	0.015	0.029	0.51
Log of normalized feed	0.261	0.045	5.73***	0.240	0.074	3.24***
Log of normalized medication/vaccination	0.108	0.019	5.66***	0.074	0.026	2.88***
Log of normalized herd size	0.345	0.060	5.72***	-0.221	0.057	-3.89***
Log of normalized concentrates	0.064	0.020	3.27***	0.468	0.056	8.37***
Log of normalized other costs	0.002	0.018	0.13	0.166	0.028	5.82***
Log of normalized land size	-0.059	0.041	-1.44	0.713	0.100	7.15***
Constant	3.461	0.785	4.41***	0.484	0.243	1.99**
usigmas	2.325	0.276	8.43***			
vsigmas	0.333	0.058	5.75***			
$\sigma^2 = \sigma^2 u + \sigma^2 v$	2.658					
$\gamma = \sigma^2 u / \sigma^2$	0.875					
Log likelihood	-441.098					
Wald chi2(7)	476.740					
R-squared				0.754		
Number of observation	379					
Returns to scale	1.6					

Source: Field survey, 2022. Significance levels legend: *, **, * represents 1%, 5% and 10% respectively**

Table 5. Hypothesis testing parameters

Test statistics	Calculated value	Critical value	Degrees of freedom	Decision
Skewness test	-2.686			
LR test for TE	119.6432	20.972	9	Reject
Skewness test	-3.11853			
LR test for EE	305.3461	24.049	11	Reject

Source: Field survey, 2022

Table 6. Distribution of Levels of Technical, Allocative and Economic Efficiency of small-scale dairy farmers

Efficiencies	Eritrea		Anseba		Debub		Maekel	
TE level	**Freq.**	**Percent**	**Freq.**	**Percent**	**Freq.**	**Percent**	**Freq.**	**Percent**
0-20	64	16.89	21	19.63	35	28.93	8	5.3
21-40	150	39.58	34	31.78	49	40.5	67	44.37
41-60	122	32.19	34	31.78	28	23.14	60	39.74
61-80	41	10.82	17	15.89	9	7.44	15	9.93
81-100	2	0.53	1	0.93			1	0.66
Total	**379**	**100**	**107**	**100**	**121**	**100**	**151**	**100**
Mean	37.37		39.29		31.57		40.65	
Std. Dev.	18.20		20.04		18.77		15.11	
Min	0.01		0.01		0.01		4.02	
Max	91.62		81.77		78.88		91.62	
AE level								
0-20	142	37.47	36	33.64	92	76.03	14	9.27
21-40	140	36.94	43	40.19	21	17.36	76	50.33
41-60	78	20.58	21	19.63	8	6.61	49	32.45
61-80	18	4.75	7	6.54			11	7.28
81-100	1	0.26					1	0.66
Total	**379**	**100**	**107**	**100**	**121**	**100**	**151**	**100**
Mean	27.24		29.02		12.23		38.00	
Std. Dev.	0.00		17.27		13.07		14.25	
Min	18.38		0.00		0.00		3.85	
Max	27.24		72.09		58.56		85.61	
EE level								
0-20	43	11.35	2	1.87	43	35.54		
21-40	32	8.44	13	12.15	30	24.79		
41-60	43	11.35	69	64.49	30	24.79		
61-80	87	22.96	23	21.5	18	14.88		
81-100	174	45.91					151	100
Total	**379**	**100**	**107**	**100**	**121**	**100**	**151**	**100**
Mean	67.60		71.17		32.24		93.39	
Std. Dev.	29.49		11.11		22.78		1.57	
Min	0.02		36.38		0.02		87.13	
Max	97.00		88.69		79.59		97.00	

Source: Field survey, 2022.
Freq: Frequency; Max: Maximum; Min: Minimum; Std. Dev: Standard deviation.

Determinants of technical Inefficiency. The analysis of factors affecting technical and economic inefficiency in Eritrean dairy farming in Table 7 reveals distinct patterns. Variables such as being a female member of a household, milking cows twice daily and operating in the Debub region showed statistical significance with positive associations with technical inefficiency at 5%, 1% and 1% levels, respectively. This implies that an increased number of female household members increases inefficiency in dairy farming in Eritrea, likewise milking cows more than once a day and operating in Debub. In contrast, longer years of dairy experience, cooperative membership, use of agricultural advisory services, and operations in the Maekel region were negatively correlated with inefficiency, all statistically significant at 1% level of probability. These efficiency-enhancing factors emphasize the role of accumulated expertise and institutional support. The study identifies critical areas for improvement, particularly addressing low farmer education levels through formal or skill-based training programs and promoting cooperative membership in regions like Anseba and Debub, where participation remains limited. While these findings align with Sultana *et al.* (2023), they contrast with conclusions from Mbehoma and Mutasa (2013), highlighting contextual variations in dairy efficiency dynamics. The results collectively underscore how farming practices, institutional engagement, and regional characteristics influence productivity outcomes in small-scale dairy operations.

The table also shows that age, educational level, Size of land mapped out for food production, extensive method of dairy farming and being a native of Debub are positively related to economic inefficiencies, depicting that the factors increase profit/economic inefficiencies of small-scale dairy farmers. Older farmers are known to be weak in agricultural activities and, as such, might not produce adequate profit efficiency. Similarly, Ogunniyi and Ajao (2010) Older farmers often resist adopting new agricultural technologies, which can limit their productivity and efficiency. This conservative approach to modern farming methods may impede their ability to optimise operations, particularly in dairy production, where technological advancements can significantly enhance profitability. Higher education, though perceived as a driver of efficiency through knowledge of better management practices, could increase profit inefficiency due to more livelihood opportunities. The prospects of more livelihood opportunities as non-farm income may reduce commitment to dairy farming by small-scale farmers Mbehoma and Mutasa (2013). Decisions to allocate a larger portion of land for food production significantly influence productivity, as expanding food crop cultivation reduces grazing areas available for dairy production, thus reducing the efficiency level of the farmers. Similarly, production methods lead to differentiated outcomes, with extensive systems using local cattle breeds yielding lower technical efficiency when compared to intensive systems adopting hybrid cows' high-productivity traits.

This study estimated the TE, AE and EE of small-scale dairy farmers in Eritrea showing deterministic and stochastic frontier methods. Generally, on average, the TE and AE of Eritrea and the selected regions were low, ranging from 31.57% to 40.65%, and 12.23 to 38.00%, respectively. However, the EE was well above 50% except in Debub that was as low as 32.24%. This shows that dairy farming in Eritrea is a profitable venture and scaling up will add to the economy and improve livelihoods of small-scale farmers who predominates the dairy sector. Increasing herd size was one of the major inputs required for technical efficiency among other inputs such as labour, feed, and concentrates. Therefore, enacting policies that would increase access to cows especially improved breeds by small-scale dairy farmer's while ensuring its affordability is an important factor for technical efficiency. Agricultural advice services are useful in assisting farmers and training them on innovative practices for enhanced dairy production, thus, encouraging farmer's utilization of these facilities will make dairy farmers not only technically efficient but allocatively efficient. Allocative efficiency of small-scale dairy farmers will result to considerable gains in dairy outputs such as milk and meat as well as their by-products and decrease cost given the available technologies

Table 7. Distribution of maximum likelihood estimation of technical and economic inefficiency determinants

Variables	Parameter estimate	Coef.	Std. Err.	z-test	Coef.	Std. Err.	z-test
	Technical inefficiency				Economic inefficiency		
Age	δ_1	-0.009	0.012	-0.73	0.026	0.014	1.82*
Sex	δ_2	-0.236	0.301	-0.79	-0.514	0.361	-1.43
Educational level	δ_3	-0.146	0.129	-1.14	0.240	0.145	1.65*
Years of dairy experience	δ_4	-0.033	0.012	-2.77***	-0.024	0.017	-1.43
Household size	δ_5	-0.069	0.068	-1.02	-0.018	0.055	-0.32
Cooperative membership	δ_6	-0.731	0.283	-2.59***	0.027	0.354	0.08
Household female member	δ_7	0.232	0.110	2.1**			
milking cow twice a day	δ_8	2.163	0.507	4.27***			
Use agricultural advise service	δ_9	-1.622	0.378	-4.3***			
Shortage of water	δ_{10}				-0.032	0.303	-0.11
Size of land mapped out for food production	δ_{11}				0.981	0.366	2.68***
Distance to nearest dairy farm	δ_{12}				0.009	0.012	0.77
Method of dairy farming: Semi-intensive	δ_{13}				0.465	0.316	1.47
Method of dairy farming: extensive					1.024	0.525	1.95*
Region: Debub	δ_{14}	0.713	0.266	2.68***	3.405	0.531	6.41***
Region: Maekel		-3.618	0.509	-7.11***	-3.230	2.815	-1.15
Constant		4.400	1.118	3.94***	-3.688	1.562	-2.36**

Source: Field survey, 2022; Significance levels legend: *, **, * represents 1%, 5% and 10% respectively**

Labour was an important factor identified for increased EE among small-scale dairy farmers along with feed, herd size and medication/vaccination. This suggests the need for increased access to and affordability of labour in the study area. Herd size was also important for efficiency in economic/profit maximization of the farmers. But increasing herd size comes with increase in feed availability and animal medication but the output elasticity for land was negatively related to EE though insignificant. Again, the size of land allocated for food production increased farmers' economic inefficiency, implying the need to improve farmers' access to land to encourage sufficient feed/concentrate production for dairy farming. Also, educated farmers tend to be involved less in dairy farming, suggesting that higher education with wide livelihood opportunities could reduce participation in dairy production, resulting in economic inefficiencies among the farmers even though the status of education of small-scale dairy farmers used in this study was very low. Using the extensive method of dairy production increases economic inefficiencies among dairy farmers. Extensive dairy farming is characterised with use of local breeds, which could jeopardize EE of dairy farmers.

Considering the regions, while dairy farming in Debub was directly linked to technical and economic inefficiencies, farmers in Maekel have higher chances of being technical and economically efficient, that is, if all the required inputs and practices are put in place. It is, therefore, important to ensure equality while interventions or projects are organised to enhance productivity and performances of dairy farming in Eritrea. Interventions should take into consideration the strengths and weaknesses of each location during implementation for effective and sustainable impacts.

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