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ESTIMATION OF THE TECHNICAL EFFICIENCY OF SMALLHOLDER DAIRY FARMERS IN SOUTH AND WEST POKOT SUB-COUNTIES, KENYA

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Abstract: **Livestock production contributes significantly to the development of the Kenyan economy. In West Pokot County, agriculture and livestock sub-sectors account for 84% of the county's economy. The sub sectors are expected to be the county's major key toward poverty reduction of 30% and a 10% annual economic growth rate. Dairy farms in South and West Pokot Sub-Counties produce less than 2 litres of milk per cow per day as compared to the national average of 8-10 litres per cow per day. This has led to household vulnerability in terms of food and income security and hence have been unable to gather for their daily needs. Therefore, this present research study was aimed at determining the level of technical efficiency in milk production among smallholder dairy farmers in South and West Pokot Sub-Counties, Kenya. The study adopted descriptive and cross-sectional research. Data was collected using a questionnaire and an interview schedule from a sample of 383 smallholder dairy farmers from five wards and 11 key informants in the two sub-counties. Descriptive results showed that the average age of the smallholder dairy farmers was 45.6 years and they owned on average five dairy cows that produced 1.97 litres of milk per cow per day. Maximum likelihood estimates results showed that a unit increase in feeding type, labour, water availability, lactation, mineral salts, animal health and silage had a positive impact on milk production per cow per day by 7.47%, 17.13%, 18.33%, 24.6%, 33.3%, 18.10% and 6.6% respectively. The mean farm technical efficiency in milk production results was 61%. The result shows that dairy farmers were inefficient in milk production. Hence milk production could be increased by 39% through better use of available resources, given the current state of technology without extra costs. Therefore, there is a need for the county and National governments to ensure that dairy farmers are trained through tailor-made dairy extension programmes.**

Keywords: **Efficiency, Technical efficiency, Smallholder dairy farmers.**

1. INTRODUCTION

The volume of cow milk produced worldwide has increased from 497 metric tonnes in 2015 to around 532 million tonnes in 2020 (Shahbandeh, 2021). According to a report by FAO, world milk production is expected to increase by 16% annually between 2020 and 2029, with roughly 16% of the world's milk production coming from India, which also produces buffalo milk, The U.S is the second largest producer accounting for about 14.6% of the global milk output, while Africa produces approximately 8- 10% of the global milk production (FAO, 2020). In most developing countries, dairy production is carried out in subsistence and smallholder systems; the animals kept are usually kept under difficult conditions, such as low inputs, minimum management enterprises and harsh environments; though they might be well adapted to such conditions they are always of low genetic makeup (FAO, 2021)

Dairy cows are very valuable and profitable for African farm families; Milk accessibility and utilization in Africa could thus hasten the attainment of sustainable development goals (SDGs) (Hill.,2017),ensure remarkable supply of nutrients, provide food security, employment and income(Mayberry et al.,2017). Although the amount produced locally increased by 16.8% between 2005 and 2017 (1.5% annually), undoubtedly because of an increase in the number of milk cows by 27% (2.5% annually), demand still outweighed supply (FAOSTAT, 2018). Southern Africa produces more milk than the rest of Africa combined. Thus, Africa is working to meet the increasing milk demand of their respective countries. The prevalence of traditional milk production methods, which account for more than 90% of the dairy output in Sub-Saharan Africa, presents another difficulty (Olaloku and Debre, 1992). The location, agro ecological zone, and socio-economic circumstances all have a substantial impact on the smallholder dairy production systems (Gizaw et al., 2016). According to Lowder et al. (2016), more than 80% of farms in SSA are smaller than two hectares.

The development of the dairy industry in Eastern Africa is impeded by a number of serious technical challenges. Generally,these limitations are particularly evident in the region's low processing capacity and utilization in the region, which is stated to be 25% in Kenya, 36% in Uganda, 29% in Tanzania, and up to 57% in Rwanda (Bingi and Tondel, 2015). The low demand for processed dairy products, particularly pasteurized milk, and their lack of diversification (more than 60% of the raw milk supply is processed into fresh, pasteurized whole milk), according to Bingi and Tondel (2015), are frequently cited as factors limiting the use of existing capacity. The loss of milk due to spoiling is also listed as a major risk for all players in the dairy supply chain, with implications for income loss and supply interruptions (Bingi and Tondel, 2015). On the other hand, there are also a number of constraints on the milk supply side. The majority of the region lacks appropriate fodder supplies, and the costs are too expensive for smallholder dairy farmers to afford. Due to this, they are unable to increase production or their milk output (CDI, 2014). Traditional practices also have an impact on the supply and demand for dairy products, which can have an impact on how well dairy value chains function (CDI, 2014). One example is the various fasting periods in Ethiopia during which no meat or animal products (including milk and butter) are consumed.

According to Thorpe et al. (2000), Kenya is habitat to over 85% of East Africa's cattle population. There are more than 1.8 million smallholder milk-producing households with one to three cows. Kenya's dairy business notably has contributed approximately 4% of the country's GDP, 14% of the agricultural sector's GDP, and 44% of the livestock sector's GDP (KDB, 2020). As a result, this industry is ideally positioned to significantly support the Kenyan government's Big Four Agenda goals of food security and nutrition, access to affordable housing, universal health care, and manufacturing. Although the dairy industry is significant, productivity in developing nations, like Kenya, is significantly lower than the global average and cannot keep up with the growing demand (Sanchez, 2010).

Though livestock in Kenya has a crucial role to play in the country’s agenda, productivity is still low, milk productivity in Kenya is far below the world averages and too low to support demand (Sanchez, 2010). According to Mugambi et al. (2015), the cost of producing milk could be reduced by about 4.4% without reducing output, and milk production in smallholder farms could be increased by 16.3% through better use of resources that are accessible given the current state of technology.

Even though dairy farming is the most important sector in South and West Pokot Sub-County’s economy, the sector is not well developed and is not contributing the expected impact on the economic growth of the county. The estimated annual milk production for the sub-Counties is approximately 6 million litres per year (West Pokot CIDP 2018-2022). The average milk produced per day is 1.8 Litres/cow (NDMA, 2022) less than the national average of 8-10 litres per cow per day. Even though the average milk production per cow per day is known, the technical efficiency in milk production among smallholder dairy farmers in the study area is unknown. Therefore, this study intended to fill this research gap by analysing the technical efficiency and its determinants among smallholder dairy farmers in South and West Pokot Sub-Counties, Kenya. The general objective of this study was to estimate the level of technical efficiency in milk production among smallholder dairy farmers in South and West Pokot Sub-Counties, Kenya. The Specific Objective was to determine the maximum likelihood estimates of the Cobb Douglas production function and to determine the distribution of technical efficiency in milk production among small holder dairy farmers in South and West Pokot Sub Counties, Kenya.

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2. MATERIALS AND METHODS

Study Area and Research design

This study was conducted in West and South Pokot Sub Counties of West Pokot County, Kenya using a descriptive and cross-sectional survey research design. These two sub Counties were preferred because dairy is a major economic activity.

Sample size and Sample Determination

A sample is a subset of the population that is chosen at random and can be used to derive general conclusions about the population (Kothari, 2004).The sample size determination was based on the formula provided by Yamane, 1967 (Equation 1).

$$n = \frac{N}{1 + N(e)^2} \quad \ldots\ldots (1)$$

Where, n = sample size, N = population and e = error term. The confidence interval used was 95% which means the level of significance (error term is 0.05) and corresponding Z value is 1.96. The probability that the sample will occur is 0.50 and will not occur is 0.50.

To find the sample size, the variables were then fitted into equation 1 as follows,

$$n = \frac{8701}{1 + 8701(0.05)2} = 383$$

Therefore, a total of 383 smallholder dairy farmers were found to be the sample size and thereby selected to be interviewed for the study.

Sampling Procedure

According to Orotho and Kombo (2002), sampling is the process of choosing appropriate participants for the study from a population such that the sampled group consists of individuals who are typical of the traits present in the total community. Therefore, this study employed purposive, two-stage cluster and simple random sampling techniques. Firstly, the study area was chosen through purposive sampling, because dairy production is one of the majority of the people's primary economic activities. Secondly, the wards formed the first stage cluster, in the second stage cluster, purposive sampling was used to select wards with the highest number of smallholder dairy farmers. Thereafter, samples were allocated for each ward by proportionate sampling technique and the smallholder dairy farmers household heads selected using simple random sampling technique as shown in Table I. The Sub-County Livestock Office provided a list of all smallholder dairy farmers from each of the two sub-counties. Using a random sample method, the names of the dairy farmers on the lists were first serially numbered before being randomly ordered and chosen. This method raised the likelihood of getting a suitable and representative sample size because it provided each farmer an equal chance of being chosen. Because the sample frame was already available as a list, this was useful (Kothari, 2004). West Pokot Sub-County has six wards namely: Riwo, Siyoi, Endugh, Sook, Mnagei and Kapenguria while Pokot South Sub-County has two wards, namely Lelan and Tapach.

Table 1: Proportionate size sample distribution per ward

Sub-County	Ward	Target Population	Proportion	Sample size
Pokot South	Lelan	2697	31	119
	Tapach	2,175	25	96
Sub-Total		4872		265
West Pokot	Riwo	0	0	0
	Siyoi	2002	23	88
	Endugh	0	0	0
	Sook	0	0	0
	Mnagei	870	10	38
	Kapenguria	957	11	42
Sub-Total		3829	100	118
Total		**8,701**		383

Source: Researcher's Own Computation from Survey Data, (2021)

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Key informants were also sampled using purposive sampling technique. They included 11 dairy cooling plant officers, 2 extension officers and 1 county livestock production officer.

Data Types and Sources

Primary data were collected directly from the smallholder dairy farmer household heads through personal interviews. Data collected included animal health, breeding services, labour size, water availability, and lactation per cow, amount of forages & concentrates, production of maize silage, number of dairy cattle, mineral supplements and feeding stall

Data Collection Instruments

A structured pre-tested questionnaire was used to collect data from the smallholder dairy farmer household heads. The questionnaire was administered by eleven trained enumerators through direct interviews among the selected dairy farmers the interview was preferred because there were illiterate respondents. Data from the fourteen key informants was collected by the use of an interview schedule.

Validity of the Data Instruments

Validity, according to Mugenda & Mugenda (2003), refers to the precision and relevance of reality and proof derived from the research findings. It is how well the informational findings from the investigation reflect the subject of the inquiry. They contend that a measurement tool is legitimate if it is capable of measuring what it claims to measure. Orodho (2009) asserts that the researcher should assess the content validity of a research instrument before utilizing it, and that the researcher should consult with colleagues and the supervisor about the instrument's items. Two specialists from the University of Eldoret evaluated the research tools for this study's face and content validity. The professionals have extensive experience in postgraduate student supervision and instruction. The instruments were modified in response to their input.

Data Collection Procedures

A research authorization letter (permit) was sought from the National Commission for Science Technology and Innovation (NACOSTI) through an introduction letter from the Directorate of Graduate Studies, University of Eldoret. The permit was presented to the Sub-County Commissioners for permission to carry out the research in the study areas. After which, the researcher and the enumerators then proceeded to make appointments with the smallholder dairy farmer household heads before collecting the field data. The household heads were interviewed. However, if the household head was unavailable, a spouse or a knowledgeable person of the household was interviewed.

Data Analysis and Presentation

Both descriptive (including percentages, means, variances, tables and graphs) and econometric methods of data analysis were used and results were presented in the form of tables. Under the econometric analysis, the Cobb-Douglas production function (stochastic frontier model) was used to estimate the technical efficiency of the smallholder dairy farmer households in milk production and to examine various variables that affected the technical efficiency of the farmers. STATA version 15 software was used for estimation. Cobb Douglas frontier production function is the most commonly used method in the empirical estimation of frontier models for its simplicity. The Trans log form is not preferred because it is susceptible to multicollinearity and degrees of freedom problems (T. J. Coelli, 1995).

Empirical model specification

The model was used in a way that was consistent with the production theory as illustrated in Equation 2 and as adopted from Coelli *et al.*, (2002) model with some modifications to fit with the cross-sectional data.

$$InYi = \beta0 + \beta1Inxi1 + \beta2Inxi2 + \beta3Inxi3 + \beta4Inxi4 + \beta5Inxi5 + \beta6Inxi6 + \beta7Inxi7 + \beta8Inxi8 + \beta9Inxi9 + \beta10Inxi10 + (Vj - Ui) \ldots\ldots\ldots\ldots (2)$$

LnY = Milk production in litres

LnX_1 = Animal health

LnX_2 = Labour (man day)

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LnX_3 = water availability

LnX_4 = number of lactations per cow

LnX_5 = amount of forage and concentrate (kg)

LnX_6 = production of maize silage (

LnX_7 = total number of dairy cattle (numbers)

LnX_8 = mineral supplements (kgs)

LnX_9 = Feeding type represented as a dummy variable, which is equal to 1 if a farmer has a feeding stall and 0 if otherwise.

LnX_{10} = Breeding services

$\beta 0$= Value of constant term

$\beta s = \beta_1, \beta_2, \ldots\ldots\ldots, \beta_{10}$, are the coefficients to be estimated.

U_i = Technical inefficiency effect predicted by the model, V_j = Stochastic error term errors assumed to be independently and identically distributed $N (0, \delta^2)$ and independent of U

The first error component V is intended to capture the effects of random shocks outside the farmer's control, measurement error and other statistical noise. The second error component U is intended to capture the effects of technical inefficiency, it is assumed to be non-negative.

The technical inefficiency effect, U_is in the stochastic frontier model could be specified in equation 3. According to Battese and Coelli (1995), the technical inefficiency effects, Ui can be expressed as in Equation 3

$$\mathbf{Ui= Zi\delta + Wi} \ldots\ldots \quad (3)$$

Where W, are random variables, defined by the normal distribution with zero mean and variance σ2 u,.Zi is a vector of social economic variables associated with technical inefficiency, δ is a (mxl) vector of unknown parameters to be estimated. The technical efficiency of the ith sample farm denoted by TE; is given as shown in equation 4

$$TE_i = \exp(-U_i = \frac{Y_i}{f(X_i \beta)\exp(V_i)} = \frac{Y_i}{Y_i^*} \quad \ldots\ldots (4)$$

Where Yi* = f(X1 β,) exp (Vi) is the farm-specific stochastic frontier. If Yi is equal to Yi* then TEi=1, reflects 100% efficiency. The difference between Yi, and Yi*is embedded in Ui.. If Ui=0, implying that production lies on the stochastic frontier, the farm obtains its maximum attainable output given its level of input. If Ui<0, production lies below the frontier-an indication of inefficiency.

The maximum likelihood estimates (MLE) of the parameters of the model, are defined by, equations 5, and the generation of farm-specific characteristics. The efficiencies are estimated using a predictor that is based on the conditional expectation of exp (-U) (Battese and Coelli, 1993). In the process, the variance parameters $\delta^2 u$, and $\delta 2 v$, is expressed in terms of the parameterization as shown in equation 5

$$\boldsymbol{\delta^2 = \delta^2 v + \delta^2 u} \ldots\ldots (5)$$

The value of σ ranges from 0 to 1 with values close to 1 indicating that random component of the inefficiency effects makes a significant contribution to the analysis (Coelli and Battese, 1996).

The technical inefficiency of farm i, i.e. ui, is the deviation from the estimated Cobb-Douglas production function, conditional upon the observed value of ε. Maximum likelihood is used to estimate the unknown parameters of the Cobb-Douglas stochastic frontier (Equation 2) and the measure of inefficiency (Equation 3) simultaneously. The likelihood function is parameterized in terms of the variance parameters, $\delta^2=\delta^2 v+\delta^2 u$ and (Battese and Coelli, 1995), in which the gamma, γ parameter has a value between 0 and 1. A value of 0 means that the deviations from the frontier are simply due to noise with no inefficiency and a value of 1 means that the deviations are entirely due to technical inefficiency.

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3. RESULTS AND DISCUSSIONS

Descriptive Analysis Results

The key descriptive results like mean, standard deviation, minimum and maximum of continuous and dummy variables are discussed under this sub-topic. Table 2 shows results related to continuous variables. These results include the respondents' characteristics such as household size, number of dependents, age of the household head, number of dairy cattle kept on the farm, income earned per day from milk sales, land size, and average milk production.

Table 2: Summary statistics of household social economic variables in the model

Factors	Mean	Standard Deviation	Minimum	Maximum
Number of household members	7.2	2.9	1.0	28.0
Number of dependents	5.5	3.4	0.0	20.0
Age of the household head	45.6	11.9	23.0	80.0
Number of dairy cattle kept on the farm	5.1	3.6	1.0	26.0
Income earned per day from milk sales	305.8	328.6	0.0	2025.0
Land size	5.25	4.8	0.1	23.0
Average milk production	1.97	2.48	0.5	20

Source: Author's Computation from Survey Data, 2021

S D –Standard deviation

From Table 2 of the results, the mean household size was about seven (7) members, ranging from one (1) to 28 members. Household size is a significant factor in labour utilization. It is believed that those depending on the household head will provide labour readily and cheaply thus lowering the production cost. As the family size increases, more labour is available for milk production, thus improving farm technical efficiency. The current result is almost similar to that by Tassew & Seifu (2009) on smallholder dairy production system and the emergence of dairy cooperatives in Bahir Dar Zuria and Mecha Woredas, North Western Ethiopia, who found that the average household size to be 8 members. Likewise, Odhiambo *et al.*, (2019) in their study in South Western Kenya, on the adaptation of smallholder dairy farmers to the effects of Climate Change, found out that the mean household size in Migori County was 7 persons. However, the current results are contrary to those of Banda *et al.*, (2021) in a study on Smallholder dairy farming contributes to household resilience, food, and nutrition security besides income in rural households who found dairy farmers' average household size to be five members.

The results further showed that the average number of household dependents was about six. From the results, there were households without dependents but some had a maximum of 20. The number of household dependents affects the household's economic performance, since if the number is too high, most of the household income will be consumed instead of being used to improve the dairy sector. This study is similar to the results of the Kenya National housing census of 2019 the average household size in West Pokot County averaged 5.3 equivalent to around 6 family members.

From the table of results, the average age of the smallholder dairy farmer household heads heads was were 45.6 years. This result is similar with to the results by Kainda (2019) on in a study on Assessment assessment of the performance of small-scale dairy farming in Meru County Kenya who found out, that the average age of the dairy farmer in Imenti Central, Meru County was about 45.7 years. However, these results were contrary to those of Maina (2018) on a study on assessing the economic efficiency of milk production among small-scale dairy farmers in Mukurweini Sub-County, Nyeri County, Kenya who found that the mean age of a dairy farmer to be 57 years. From a study by Banda et al,. (2021) on a study on smallholder dairy farming contributes to household resilience, food, and nutrition security besides income in rural households in Malawi it was documented that, there were few young farmers involved in dairy production and this could be due to lack of start-up capital and the high labour demand associated with the cut and carry dairy feeding systems that was were used. This could also be an indication of the need for deliberate mechanisms to stimulate more entrants into dairy farming and hence avert the dwindling of number of farmers in dairy farming over time. For instance, tailor-made training for older dairy farmers could be introduced in order to improve on their technical efficiency. The technical efficiency of dairy farmers reduces with age. Farmers below 40 years tend to do better than those above 40 years (Stein & Amanda, 2015).

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Further, results in Table 2 show that the mean number of dairy cattle kept on the farm by smallholder dairy farmers in the study area was five (5). The smallest herd size was one while the largest herd size was 26. From a study on the technical efficiency of dairy farms in Eastern Central Highlands, Kenya by Mugambi *et al.*, (2014), it was found that with an increase by one unit in the size of the milking herd size, there was a corresponding increase in smallholder dairy farm performance by 6%. The more the herd size is increased, the more milk is produced.

The results in Table 2 on income earned per day from milk sales ranged from Ksh 0.00 to Ksh 2,025.00. The average income earned per day was Ksh 305.80. This showed that the dairy business was running at low-profit margins and some even getting losses. In a study by Mcdonald *et al.*, (2007) on profits, costs and the changing structure of dairy farming, it was found that small farms were unable to earn enough to replace their capital. While larger farms were more profitable due to reducing costs in the long run costs

Table 2 of results showed the farmer with the largest land acreage had 23 hectares while, the lowest was 0.1 hectares. This result is almost similar to those from the County Government of West Pokot which reports that the land size in the county is 5 hectares and 25 hectares for small farmers and large-scale farmers respectively (West Pokot County Annual Development Plan, 2020/2021.)

Table 2 of the results further shows that average milk production was 1.97 litres per cow per day, the lowest being 0.5 litres and the maximum milk production per cow per day was 20 litres. This result is contrary to the results by the Kenya Dairy Board (2020) that the average milk production in Kenya is 7.9 litres.

Table 3 shows the gender of household heads of the smallholder dairy farmers. The results show that 89.3% of household heads were male-headed while 10.7% were female-headed households. These results concur with those of Wilkes *et al.*, (2020) in a study on variation in the carbon footprint of milk production on smallholder farms in central Kenya, which reported that 85% of the dairy farmers were male-headed. According to the study by Kimaro *et al.*, (2013), regardless of female's many responsibilities in dairy production, women have significantly less access to resources and services which impairs their increased productivity and their income earning potential. Failure to access resources is more likely to constrain women's participation in smallholder dairying even in situations where women are the main dairy operators (Tangka *et al.*, 1999)

Table 3: Gender of the household heads sampled

	N	%
Female	41	10.7
Male	342	89.3
Total	383	100.0

Source: Author's Computation from Survey Data, 2021

Table 4 of the results show the level of education of the smallholder dairy farmer household heads. From the results, 44.9% of the smallholder dairy farmer household heads had attained a primary level of education, 30% secondary education level, and 15.4% tertiary level, while 9.7% had no formal education. The results indicate that the highest percentage of the farmer households' heads in the study area had attained primary and secondary levels of education this shows that farmers who have basic levels of education are more likely to be directly involved in dairy production, which is the main source of income in the rural areas. This result concurs with those of Koech (2011), in a study on the relationship between farmer's educational attainment and milk production in Eldama Ravine Division, Koibatek District in Baringo County. The study found that 49% of the respondents had secondary education. This was followed by 23% with primary, 11% with certificate training and 2% with master's degree levels of education. Formal education and training provide a route for the acquisition of useful knowledge on dairy production due to the ability to read and comprehend information on agricultural activities (Odhiambo et al., 2019).

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Table 4: Level of Education of the Smallholder Dairy Farmer Household Head

	Level of education	Frequency	Percentage
The level of education	None	37	9.7
	Primary	172	44.9
	Secondary	115	30.0
	Tertiary	59	15.4
	Total	383	100.0

Source: Author's Computation from Survey Data, 2021

ECONOMETRIC ANALYSIS

Estimates of Level of Technical Efficiency in Milk Production among Small Holder Dairy Farmers

Table 5 of the results shows the coefficient of determination (adjusted R-squared) that was computed to determine the degree to which the input variables (predictor variables) explained the variation of the output variable (predicted variable). The Results revealed that the R-Squared and Adjusted R-Squared values were 0.91 and 0.88 respectively. The R-Squared result of 0.91 means that the independent variables for the current study explain 91% of the variability of the dependent variable, whereas the Adjusted R-Squared value of 0.88 means that 88% of the variation in the output variables is explained by the input variables and only 12% lies within the error term in the regression model for this study. This indicates a perfect goodness of fit for the regression model. According to Wooldridge (1991), adjusted R-squared ranges from 0 to 1, and a coefficient of determination of 0.7 to 1 is acceptable.

Table 5: Coefficient of Determination

R	R- Square	Adjusted R –Square	Std. Error of the Estimate
0.952	0.906	0.875	12.5000

Source: Author's Computation from Survey Data, 2021

Table 6 shows the results of the maximum likelihood estimates of the Cobb-Douglas stochastic frontier production function. From the table of results, the Log likelihood ratio (LR) was found to be -94.501472 with a p-value of 0.0000 and therefore, statistically significant at a 5% level. This Log likelihood ratio test detected a statistically significant inefficiency term in the model, hence indicating that inefficiency exists in the data set. Thus, clear evidence of failure to accept the null hypothesis of no inefficiency component in the model and accept the alternative hypothesis that an inefficiency component exist in the model. The sigma-squared, gamma and log-likelihood variance parameters provide results on the behaviour of the error term and the model goodness of fit. The variance parameter gamma is a ratio of inefficiency error term ($\delta u2$) to the total sum of errors ($\delta u2 + \delta v2$), that is, $\gamma = \delta u2 / (\delta u2 + \delta v2)$. The variance related to the inefficiency effect γ in this case, was about 100% of the total variance. The frontier showed there were no stochastic random errors. This result implies that the one-sided error (inefficiency) is a major component of the total variance and that 100% of the observed variance among smallholder dairy farmer households was because of differences in their technical efficiencies. The gamma value should fall between 0 and 1, with 0 indicating that OLS is the best estimator since there is no stochastic noise and 1 indicating that maximum likelihood efficiency estimates should be used because there is no random noise. The use of maximum likelihood estimates was suitable in this study since the variance parameter gamma had a value of 1. The value was also significant at 5%, an indication that there was inefficiency in dairy milk production among the smallholder dairy farmers in South and West Pokot Sub Counties.

From Table 6 of the results, the coefficients for the feeding type, labour, water availability, lactation and mineral salts and silage were positive in the production function, all these variables were found to be statistically significant. The positive coefficients of variables are an indication of increased production with an increase in the variable proportions of these variables, this ceteris paribus, agree with the law of variable proportions and non-negativity assumption in the production function. The number of dairy cattle, forage, concentrate and animal health had negative coefficients and were found to be statistically significant.

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Table 6: Maximum Likelihood Estimates of the Cobb-Douglas (Stochastic Frontier Production Function) Results

Stoc. frontier normal/truncated-normal model			**Number of observations =383**			
			Wald chi2(10) = 8.00e+08			
Log likelihood = -94.501472			Prob > chi2 = 0.0000			
log production	**Coefficient**	**standard Error**	**Z**	**P>|z|**	**[95% interval]**	**confidence**
log feeding type	0.074653	0.015528	4.81	0.000*	0.044219	0.105087
log breeding services	-0.01828	0.094332	-0.19	0.846	-0.20317	0.166608
Log Number of dairy cattle	-0.03085	0.01248	-2.47	0.013**	-0.05531	-0.00639
Log Labour man-days	0.171339	0.013761	12.45	0.000*	0.144367	0.198311
Log Water availability	0.1833	0.009398	19.5	0.000*	0.164887	0.201728
Log Forage concentrate	-0.04254	0.025451	-1.67	0.095***	-0.09242	0.007343
Log Animal health	0.18095	0.101429	1.78	0.074***	0.37975	0.019843
Log Lactation	0.24582	0.00284	86.560	0.000*	0.240235	0.255137
Log Mineral salts	0.33257	0.012091	27.5	0.000*	0.308874	0.356272
Log Silage	0.06644	0.003108	21.38	0.000*	0.072542	0.060351
Constant	3.42151					
/mu	0.424702	0.037159	11.43	0	0.351871	0.497533
/lnsigma2	-1.7106	0.093133	-18.37	0	-1.89314	-1.52806
/lgtgamma	30.7239	191.7794	0.16	0.873	-345.157	406.6046
sigma2	0.180758	0.016834	0.150598	0.21695		
gamma	1	8.69E-12	1.30E-150	1		
sigma_u2	0.180758	0.016834	0.147763	0 .2137525		
sigma_v2	8.21E-15	1.57E-12	-3.08E-12	3.09E-12		

Legends

n= 383 | Prob > chi^2 = 0.0000

Wald chi2(10) = 8.00e+08

Log likelihood = -94.50

LR test for: H0 : Technical Inefficiency does not exist

Ha: Technical Inefficiency exits

0.000* = significant at1% level and 0.05**=significant at 5%, *** = significance at 10%

Source: Authors conceptualization from survey data, 2021.

From table 6 of results From Table 5 of results, feeding type, depicted by whether a farmer had a feeding stall or not, had a positive coefficient of 0.07. This result was statistically significant at 1% significance level. This showed that an increase in the use of feeding stalls by 1 increased milk production by 7%. This indicates that there is an efficiency gap to increase milk production by increasing the feeding stalls. Similar results were found by Devries and Keyserlingk (2006), in an article on ‘Feed stalls affect the social and feeding behaviour of lactating dairy cows.’ The results indicated that providing increased feed stalls, would improve access to the feed and reduce competition at the feed bunk, particularly for subordinate cows. The results were also in convergence with a study by Hadush (2021) on the impact of stall-feeding practices on household welfare in Tigrai Ethiopia. The study found that there would be a 21% decline in milk production and productivity if adopters would not have adopted the technology while non-adopters were estimated to increase their milk production by 100% and productivity by 48% if they would adopt the technology.

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From Table 6 of the results, at a 5% level of significance, the number of dairy cattle had a negative coefficient of 0.03 and was statistically significant. This demonstrated that milk output would decrease by 3% with an increase in the number of dairy animals. This indicates that there is no efficiency gap to increase milk production by increasing the number of dairy cattle. The reason might have been that with a high number of dairy cattle populations, competition for scarce available resources like feeds and water would lead to inadequate feeds. This will lead to decreased milk production. A small dairy cow herd size can easily be manageable in terms of animal welfare and dairy health hence the probability of increased milk production. These findings disagree with those made by Barkema et al. (2015) in a research on how changes in the dairy business have affected health and welfare, who discovered that while herd size has increased. Dairy farms increasingly rely on hired (nonfamily) labor. In order to reduce human error and assure uniformity of methods, regular professional contact and the adoption of farm-specific norms are important. Due to genetic selection for milk production as well as advances in diet and management, the average amount of milk produced per cow has gone up. Contrary results were also found by Kenya Dairy Board (2021) in a study on the Cost of milk production in Kenya. It was discovered that there is a need to expand the herd since a small herd may restrict the profitability of the dairy business, necessitating the requirement for a viable unit.

Further, results in Table 6 on man-hour labour was significant at a 1% significance level. Man-hour labour (amount of work performed by the average worker in one hour) had a positive coefficient with a value of 0.17. This implies that a unit increase in man-hour labour applied in milk production would result in an increase in milk output by 17 per-cent. Similar results were found in the Irish dairy system by Deming et al., (2019) in a study on the effects of labour efficiency on the profitability of grass–based seasonal-calving dairy farms. It was found that maintaining the farm hours worked per day while utilizing the same strategies and increasing herd sizes resulted in profitable options. However, contrary results were found by Stankov (2020) in a study on the labour productivity of dairy cattle farming in central and southeast Bulgaria .The results of the study indicated that large and huge farms are distinguished by high labour productivity. The income from production, profit, milk quantities, and the cost of one annual work unit (AWU) and a man-hour was several times higher compared to small and medium farms. Production was organised at a much better technological level, which was a contributing factor towards high-quality and competitive milk production.

Results further show that water availability was statistically significant at a 1% significance level with a positive coefficient of 0.18. This shows that a one-litre increase in water availability will lead to an increase in milk production by 18%. This shows that water availability is an important factor in milk production among the smallholder dairy farmers in the study. Meehan (2015) in a study on livestock water requirements, found that milk contains 87% of water and that water consumed by a dairy cow is 30 to 50 gallons per day (one gallon is approximately 3.8 litres). Similar results were found in a study by Daros et al., (2019) on a study-on readily available water access associated with greater milk production in grazing dairy herd. The study found that herds with unrestricted access to drinking water produced more milk than herds with restricted access to drinking water. Similarly, Devi *et al*., (2020) on a study on Water Use and Dairy Production System: An Indian Experience, found out that, milk production is challenged by increasing water scarcity and simultaneously growing demand for food and feed.

Results from Table 6 showed that amount of forages and concentrates had a negative coefficient of 0.04 though statistically significant at a 10% level of significance. This indicates that there is no efficiency gap to increase milk production by increasing the amount of forages and concentrates. This current result might be due to failure to feed cows with the correct forage and concentrate ration per day. Contrary results were found by Lawrence et al, (2015) on the effect of concentrate feeding amount and feeding strategy on milk production, dry matter intake, and energy partitioning of autumn-calving Holstein-Friesian cows. It was found that cows on the higher treatment had a higher total daily milk production (TDMI) of (18.7 ± 0.36 kg/cow per day) compared with cows on the Low treatment (15.8 ± 0.36 kg/cow per day). It was further argued that by increasing the total amount of concentrate offered, cows had higher TDMI and energy intake, which resulted in increased milk production and reduced negative energy balance and body condition score loss. Differing results were also found by Pretz (2016) in a study on improving feed efficiency through forage strategies for increasing dairy profitability and sustainability, which found that a high forage ration lead to increased milk productivity.

Table 6 of results further shows that animal health had a positive coefficient of 0.18.This result was significant at a 10% significance level. Animal health is an important factor in increased milk production. Similar results were found by Vinitchaikul et al., (2023) in a study on the impact of lumpy skin disease outbreaks on monthly milk production on dairy

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farms in Khon Kaen, Thailand. This study demonstrated that lumpy skin disease outbreaks on dairy farms resulted in significant farm milk production losses. Additionally, Džermeikaitė et al., (2023) on a study on Innovations in Cattle Farming: Application of Innovative Technologies and Sensors in the Diagnosis of Diseases. It was found that, when biosensors are used to detect diseases early, the epidemiological curve can be moved to the left because quick action can be taken to stop the spread of the disease and its negative effects on production, society, and the economy.

Table 6 of results further shows that the lactation of a dairy cow in the study area had a positive coefficient of 0.25 and was statistically significant at a 1% significance level. An increase in the number of lactations of a dairy cow results in a 24.58% increase in milk production. Similar results were found by Viyajakumar et al., (2017) in a study on the effect of lactation number, stage, length and milking frequency on milk yield, in Korea. The results showed the trends of total milk yields from each lactation number of the Holstein cows increased gradually from 1 to 3 lactations. Habibi et al., (2021) in a study on the effect of season and lactation number on milk production of Holstein Friesian cows in Kabul Bini-Hesar Dairy Farm, reported that milk yields of individual cows gradually increased from 1st to 3rd lactation. The highest milk yield was recorded in 3rd lactation and the lowest was in the 1st lactation. Moawed et al., (2022) in a study on the estimation and interpretation of ordered logit models for assessing the factors connected with the productivity of Holstein–Friesian dairy cows in Egypt. Results showed that cows with younger ages at first calving produce two times higher milk quantities. Also, longer days open were associated with higher milk yield. The highest amount of milk yield was denoted by higher lactation periods (> 250 days). The peak yield per kg was significantly related to the actual yield ($P < 0.05$). Moreover, shorter dry periods showed about 1.5 times higher milk yield.

Table 6 of results further show that; mineral supplements had a positive coefficient of 0.33 and the results were statistically significant at a 1% significance level. This showed that there would be a 33.26% increase in milk production when the amount of mineral salts fed to dairy cows is increased by one kilogramme. Mugambi et al., (2015), reported similar results in a study on the assessment of the performance of smallholder dairy farms in Kenya: an econometric approach. They found that mineral supplements had a positive coefficient of 0.28 and were statistically significant at a 1% level. Contrary results were reported by Jones et al., (2013) in a study on the effect of trace mineral sources on reproduction and milk production in Holstein cows. He found that milk production and composition were not affected by mineral supplements fed.

Further, table 6 shows the results of silage production in kilograms. Silage production had a positive coefficient of 0.067 and was statistically significant at a 1% significance level. This result shows that the use of silage on smallholder dairy cow production causes 6.644% of milk production. Similar results were reported by Waziri and Uliwa (2020) in a study on Feeding Dairy Cows with Maize Silage and its Effect on Milk Production and Milk quality in Hai District. The results indicated that feeding maize silage to dairy cows led to an increase in milk production, by 50% from 10 to 15 litres per day during the experiment. Similar results were also reported by Yilmaz et al., (2020) who found that silage fed to dairy cows leads to increased milk production, which suggests that the differences in the level of efficiency observed among dairy farms are explained by the use of maize silage. Brar et al., (2016) also found similar results in a study on maize silage feeding vis-a-vis milk production in crossbred dairy cows in the Tarn Taran District of Punjab. In the study, it was found that feeding maize silage of 32kg/animal/day improves milk production of cross-bred dairy cows by 15.5%.

Distribution of Technical Efficiency

Table 7 of results shows the results on the distribution of technical efficiency estimates for technical efficiency of milk production among smallholder dairy farmers in South and West Pokot Sub Counties. In this study area, the predicted technical efficiency indices had variations among smallholder dairy farmers that ranged from 0.21 to 1.00.

Table 7: Frequency Distribution of Technical Efficiency of Dairy Farmers

Efficiency class	Frequency	Percentage	Cumulative
0.01 – 0.3	175	45.69	45.69
0.31 – 0.60	179	46.74	92.43
0.61 – 0.90	29	7.57	100
Total	383	100	
Mean Efficiency	0.6104363		
Minimum	0.2061551		
Maximum	0.9999996		
Standard deviation	0.1911591		

Source: Researcher's own calculation from Survey Data, 2021

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From the results, the technical efficiency of the smallholder dairy farmers in the current study ranged from 21% to 100% with a mean efficiency of 61%. This implies that the farmer with the best dairy production practice had a technical efficiency of 100% and the farmer with the worst practice had a technical efficiency of 21%. This means that smallholder dairy farmers in the study area are falling below the production possibility frontier. The technical efficiency ranges from 0% to 100%. The average technical efficiency score (mean estimate) of 61% for this current study indicates that there is a scope for increasing technical efficiency by 39% in the short run using the current input quantities under the existing technology so as to be technically efficient at 100%. This mean efficiency level indicates that only a small fraction (39 per cent) of the output can be attributed to wastage. According to the study by Färel and Lovell (1978), on the input and output approach of measuring the technical efficiency of production, a production technology transforming inputs reported that farmers are said to be technically efficient if the minimum and maximum technical efficiencies for farmers are between 80-94% and 95-100%, respectively, with a mean technical efficiency falling between 95-98%. Hence, only 2-5% of the potential frontier output is not realized due to uncontrollable factors beyond the farmer's capabilities. This is a sufficient and necessary condition, if and only if, the production technology is linearly homogenous. Therefore, the results of this current study do not meet the sufficient and necessary conditions. This indicates that smallholder dairy farmers in the study area are technically inefficient in their production.

According to the study by Ahiele *et al.,* (2019), on technical efficiency analysis of broiler production in the Mampong Municipality of Ghana, they found out that individual levels of technical efficiency ranged between 42% and 99% with a mean of 87%. The farmers with the best practice had a technical efficiency of 99% while the farmer with the worst practice had a technical efficiency of 42%. This shows that in the short run, poultry farmers can still increase the efficiency of resources used at the farm level by 13% from a given mix of production inputs and production technology. Therefore, the findings of the current study are in convergence with the findings by Mugambi *et al*., (2014) on the technical efficiency of dairy farms in Eastern Central Highlands, Kenya. They reported the mean farm technical efficiency as 83.7%, implying that milk production could be increased by 16.3% through better use of available resources, given the current state of technology without extra cost. Similar results were reported by Bahta et al., (2021) in a study in Tanzania on an analysis of technical efficiency in the presence of development toward commercialization. The study found the average technical efficiency to be 80%. Similar results were also found by Yilmaz, Gelaw and Spelman, (2020), in a study on the analysis of technical efficiency in milk in a study done in the West Mediterranean Region of Turkey. It was found that the technical efficiency of the dairy farmers ranged from 0.30 to 1.00. The mean efficiency was 0.55, indicating the presence of substantial scope for improving the competitiveness of the dairy sector in the region by improving the efficiency of farmers.

4. CONCLUSIONS AND RECOMMENDATIONS

Descriptive results showed that on average the dairy farmer households were aged 45.6 years and owned five dairy milking cows that produced an average of 1.97 litres of milk per cow per day, which is less than the national average (8-10 liters per cow per day). From the results, 89.3% of the smallholder dairy farmers were males while 10.7% were females. The majority of them had primary education (44.9%) and secondary education (30%). Stochastic production function results on the effects of technical efficiency in milk production revealed that an increase by one unit of feeding type, labour, water availability, lactation, mineral salts, animal health and silage had a positive impact of 7.47%, 17.13%, 18.33%, 24.6%, 33.3%, 18.10% and 6.6% respectively on milk production per cow per day. Additionally, an increase by one unit in the number of dairy cattle, amount of forages & concentrates had a negative impact of 3.08% and 4.25% respectively. The mean farm technical efficiency in milk production results was 61%, with a minimum and maximum technical efficiency score of 21% and 100% respectively. This shows that smallholder dairy farmers in the study area were inefficient implying that milk production could be increased by 39% through better use of available resources, given the current state of technology without extra cost. Therefore, to reduce the efficiency gap in milk production among smallholder dairy farmers, there is a need for the county and National government to ensure that dairy farmers get given informal as well as formal education so that their skills and entrepreneurial ability will be improved. This is particularly on silage production, zero grazing and benefits of few productive cows (pedigree), the importance of feeding a cow with mineral salts and supplements, and understanding the benefits of labour productivity. In addition, to ensure educative programmes on how to increase dairy cows' lactation are availed to the farmers. This will ensure there is increased milk production in the country. The county and national governments should also ensure extension programmes are redesigned appropriately and be made to reach the dairy farmers to attain their objective so that farmer's technical efficiency will be increased. Extension programmes should also be tailored towards making feeding stalls, ensure more animal health officers are deployed to different wards, and ensuring drugs for livestock treatment are subsidized and within farmers' reach. The farmer should also be trained on the importance of good and high-quality forages and concentrates, demo farms in each ward should as well be planted.

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Competing Interest Statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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