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TECHNICAL EFFICIENCY AND PROFITABILITY OF SMALLHOLDER DAIRY CATTLE FARMING POST-FMD: A STOCHASTIC FRONTIER ANALYSIS IN WEST JAVA

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Abstract

Background: The study is motivated by the persistent low productivity of dairy cattle farming in Bogor Regency, specifically within the Kawasan Usaha Peternakan (KUNAK), which has been further aggravated by the Foot and Mouth Disease (FMD) outbreak and inefficient input management in the area. The sector faces significant challenges, including the dominance of smallholder farms with poor feed management, shrinking land for forage, and heavy reliance on imports, all of which weaken local farmers' bargaining power.
Purpose: This study aimed to analyze the factors influencing milk production, technical efficiency, and farm profitability in KUNAK. It seeks to evaluate how effectively farmers manage inputs, such as cattle and feed, to maximize output and determine the financial feasibility of these operations post-FMD.
Design/methodology/approach: Data were collected from 67 purposively sampled farmers in Cibungbulang and Pamijahan (January–April 2025) who owned cows in their second or third lactation. This study utilized a stochastic frontier translog production function estimated via Maximum Likelihood Estimation (MLE) to measure technical efficiency, alongside a revenue-cost (R/C) ratio analysis for profitability.
Findings/Result: MLE results indicated that lactating cows (0.656), concentrate (0.193), and tofu dregs (0.159) significantly affected milk yield. Conversely, labor's negative elasticity (-0.083) reflects severe overutilization. The farms operate under increasing returns to scale, with a high mean technical efficiency of 0.868. Efficiency improves with farmer age but declines as the number of family dependents increases. While economically feasible (R/C ratio=1.10), operations face tight profit margins of Rp207,951 per head per month.
Conclusion: Although smallholder dairy farming in the KUNAK cluster demonstrates high technical efficiency (0.868), this operational mastery does not translate into proportional economic welfare due to low market pricing and high input costs. Policy interventions must target labor reallocation and cooperative pricing reforms to bridge the gap between technical proficiency and economic sustainability.
Originality/value (State of the art): This study contributes a post-FMD analysis of smallholder dairy clusters, revealing a critical disconnect where high technical efficiency does not guarantee economic welfare due to external market and institutional failures.

Keywords: dairy cattle, production function, profitability, stochastic frontier, technical efficiency

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INTRODUCTION

The livestock sector serves as a vital component of the Indonesian economy by contributing significantly to the gross domestic product; however, the dairy subsector currently faces a critical deficit in fulfilling national nutritional demands. This deficit is primarily evidenced by a continuous downward trend in national milk production, which experienced a significant reduction of 12.89% in 2022 and dropped further by 4.47% in the following year, as shown in Table 1. While domestic production volumes have steadily decreased to 824,273 tons in 2022 and 787,374 tons in 2023, per capita milk consumption across the country has remained stagnant. Consequently, the total domestic milk yield can only satisfy 21% of the total national consumption requirement, creating a massive supply shortage within the local market. To fill this extensive nutritional gap, the government enforces a heavy dependence on imports to cover the remaining 79%, a policy that inherently weakens the bargaining position of local farmers and consistently suppresses milk prices at the farm level.

The Foot-and-Mouth Disease (FMD) outbreak, which began in April 2022, has further exaggerated the situation, causing a population decline of up to 118,148 heads and respective production decreases of 12.9% in 2022 and 8.49% in 2023. Consequently, smallholder farmers have experienced significant economic losses. Although Ministry of Agriculture (2025) targets an increase in the dairy cattle population to 1.8 million head and productivity to 20 L/head/day, the realization remains far from expectations. Java accounts for 98.43% of the national dairy cattle population, with West Java being the second-largest milk producer. In 2023, production reached 268,467.30 tons from 110,005 heads of cattle, distributed across Bandung, Bandung Barat, Garut, Kuningan, Subang, and Bogor (BPS, 2024).

Table 2 shows that Bogor Regency is one of the main milk producers in West Java, with Kawasan Usaha Peternakan (KUNAK) serving as a government-supported dairy farming development center aimed at increasing national production (Putri et al. 2024). However, data from KPS Bogor (2024) reveal a drastic decline in the number of farmers, from roughly 800 in 2009 to only 100–150 in 2024, leading to a drop in daily milk production from 20–25 tons to 14 tons per day. This situation signifies a challenge to the sustainability of smallholder farming. Several previous studies have highlighted aspects of technical efficiency, production factors, and income (Ariska et al. 2024; Priambodo 2024). Therefore, this study was conducted to analyze the production factors, technical efficiency, and profitability of dairy farming in KUNAK as a contribution to the enhancement of livestock agribusiness. Moreover, data from the Bogor Regency Office of Fisheries and Livestock (2024) show instability in the dairy cattle population and milk production across 40 sub-districts in Bogor Regency during 2020–2023.

Figure 1 indicate a significant drop in both the dairy cattle population and milk production in Bogor Regency during 2022. The dairy cattle population in Bogor Regency experienced a sharp 39.2% reduction, falling to 5,792 heads in 2022 from 9,538 heads in 2021. This decline in the livestock population is presumed to be an outcome of the Foot and Mouth Disease (FMD) outbreak in Indonesia, which infected 20,723 cows across 16 provinces during its initial spread (Ditjen PKH, 2024). The reduction in the dairy cattle population corresponded to a significant 39% drop in milk production. Dairy milk production in Bogor Regency was 14,420 tons in 2022, whereas it reached 23,741 tons in 2021. Both the dairy cattle population and milk production began to build up in 2024, as indicated by the graph in Figure 1. This situation undoubtedly affects farmers' income, as revenue is influenced by the number of lactating animals and the amount of milk produced (Ervina et al. 2019).

One of the largest milk-contributing dairy farming areas in Bogor Regency is KUNAK. Productivity in KUNAK is measured low, with an average milk production of only 8–10 L/head/day (Malau and Winandi, 2017; Karuniawati and Fariyanti, 2017), compared to dairy farms in Lembang District, which can achieve 16.04 L/head/day (Malau, 2017). This indicates that the application of production factors in KUNAK is inferior. Other contributing factors include a lack of adoption of technology, poor feed management, and a shortage of skilled labor capable of efficiently managing feed and livestock (Karuniawati and Fariyanti, 2017). This indicates that the performance of dairy farms in KUNAK is inferior, despite the application of regional and clustering approaches.

Theoretically, the development of farm clusters is expected to increase efficiency, productivity, and profitability through mechanisms such as economic agglomeration, enhanced access to inputs, knowledge transfer, and strengthening farmers' bargaining power (Porter, 1980). Cluster institutions, such as cooperatives and farmer groups, serve as connections between farmers and production resources, as well as other supporting subsystems (Astuti et al. 2010; Wardani 2009). The Foot-and-Mouth Disease (FMD) outbreak in 2022 exacerbated the productivity and efficiency of farmers. This situation could have been helped by the role of cluster institutions, for example, through collective vaccine procurement, technical assistance, and business risk mitigation (Astuti et al. 2010). However, this role has not been optimally utilized in KUNAK, leaving farmers to face horrific obstacles in sustaining their farm performance. Furthermore, farmers are trapped in a situation where a high technical efficiency score does not translate into significant economic welfare due to external market failures, such as stagnant milk prices and rising input costs.

This situation is exacerbated by the increasing difficulty in procuring production inputs, such as animal feed and labor. Land available for forage (HMT) is also shrinking because of land conversion to tourism areas, accommodations, and commercial buildings. This condition forces farmers to purchase high-quality forage, such as elephant grass or corn leaves, at relatively high prices, thereby increasing the production costs (Noviana, 2020). Tofu dregs, often used as a booster in concentrate mixtures, frequently suffer from poor quality, such as being too wet, having a sour odor, or possessing a yellowish color. The rise in concentrate feed prices, which is not proportional to the increase in milk selling prices, also decreases farmer profits, as production input costs escalate without a significant corresponding increase in revenue. This structural constraint is not unique to Indonesia; recent global studies indicate that smallholder dairy farmers in developing urban and peri-urban regions similarly struggle with severe efficiency drops due to exorbitant commercial feed costs and market failures (Tosun, 2024).

However, most existing studies focus on pre-pandemic conditions or general production functions without accounting for the severe structural shocks caused by the recent FMD outbreak. This research offers novelty by analyzing the post-FMD landscape in a specific government-supported cluster (KUNAK), which reveals a critical disconnect where high technical efficiency does not necessarily translate into economic welfare. Furthermore, this study investigates the specific impact of alternative feeds, such as tofu dregs, in a resource-constrained environment, providing a more granular view of the survival strategies employed by smallholders in West Java.

Table 1. Milk Consumption, Production, and Dairy Cattle Population in Indonesia (2018–2023)

Period	Production (tons)	Consumption (tons)	Dairy Cattle Population
2018	951,003.95	4,267,320	581,822
2019	944,537.08	4,355,080	565,001
2020	946,912.81	4,332,880	568,000
2021	946,388.17	4,385,730	582,169
2022	824,273.20	4,420,000	507,075
2023	787,374.38	4,534,387	464,021

Source: BPS (2024)

Table 2. Dairy Cattle Population by Regency/City in West Java (2022)

District	Dairy Cattle Population	Production (tons)	Productivity (tons/head)
Bandung	38,491	54,436.87	3.87
Bandung Barat	24,306	68,867.06	7.76
Garut	14,419	29,134.24	5.54
Kuningan	7,864	16,548.90	5.77
Subang	6,645	21,836.99	9.00
Bogor	5,849	15,184.56	7.11

Source: BPS (2024)

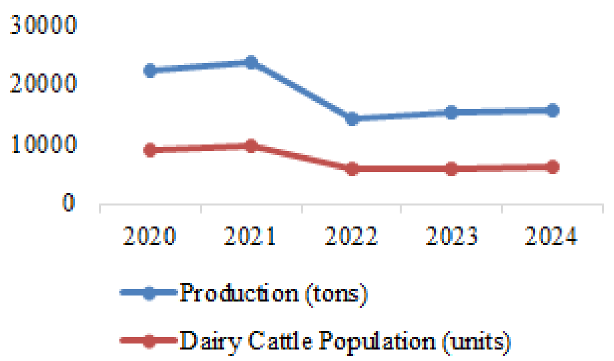

Figure 1. Dairy cattle population and milk production in Bogor Regency (2020–2023)

Grounded in Farrell's (1957) framework of efficiency, the measurement of agricultural performance necessitates a clear distinction between random external shocks and managerial inefficiency. While extensive literature has evaluated the general production functions of dairy farming, there remains a critical theoretical and empirical gap regarding the efficiency dynamics of state-supported farm clusters recovering from severe structural shocks, such as the 2022 Foot and Mouth Disease (FMD) outbreak. Previous studies have predominantly focused on pre-pandemic conditions without adequately positioning smallholder resilience within the stochastic frontier paradigm. This study addresses this gap by integrating production economics theory with an empirical assessment of how post-shock input constraints affect both the production frontier and the determinants of technical inefficiency.

To address the issues of low productivity and economic stagnation, this study employed a quantitative approach to evaluate the technical and economic performance of dairy farms. We approach this problem by modeling the production process using a Stochastic Frontier Analysis (SFA) with a transcendental logarithmic (translog) function to capture the complex interactions between inputs. This method allows for the simultaneous estimation of production elasticities and technical inefficiency effects caused by managerial or socioeconomic factors. The study also addresses the question of economic feasibility by calculating the revenue-cost (R/C) ratio and assessing profitability over both cash costs and total costs. By integrating these two analytical frameworks, the research can pinpoint whether the root cause of farm distress lies in the technical mismanagement of inputs or external market failures, such as price setting.

Based on the previously mentioned issues, it can be concluded that farmers in KUNAK, Bogor Regency, face numerous constraints, resulting in low productivity and efficiency. This verdict contradicts the theory of cluster institutions, which posits that such structures should increase both aspects of innovation. Therefore, the objectives of this study are to analyze the factors resulting in dairy milk production in KUNAK, as well as its levels of technical efficiency and profitability.

METHOD

This study was conducted from January to April 2025 in KUNAK, located in Cibungbulang and Pamijahan Districts, Bogor Regency. This location was selected as it is the center of milk production in the region. The research stages included data collection and processing, proposal development and final writing. The data used were both primary and secondary sources. Primary data were acquired through observations and interviews using a questionnaire. Secondary data were sourced from Badan Pusat Statistik (BPS), the Ministry of Agriculture, Ditjen PKH, and various literature sources.

The data collection process employed a survey method using a structured questionnaire administered to a specific group of respondents in the study. The sampling technique used was purposive sampling, selecting 67 active farmers located in the Cibungbulang and Pamijahan districts who were members of the KUNAK cluster. A critical criterion for respondent selection was the ownership of lactating cows currently in their second or third lactation periods, as these periods are scientifically recognized as peak production phases for dairy cattle. This specific inclusion criterion ensured that the efficiency analysis was based on the optimal physiological potential of the livestock, minimizing bias from low-producing first-lactation cows or aging cattle (Nurhayu et al. 2017). The sample size of 67 respondents fell within the recommended statistical range for this type of agricultural study, ensuring representativeness for the specific cluster.

To determine the factors influencing milk production, a Stochastic Frontier Analysis (SFA) was performed using the Transcendental Logarithmic (Translog) production function with FRONTIER 4.1 software. The Maximum Likelihood Estimation (MLE) method was selected over Ordinary Least Squares (OLS) to simultaneously estimate the parameters of the production function and the technical inefficiency effects model. To estimate the stochastic production frontier, the independent variables, which are the number of lactating cows (X1), forage (X2), concentrate feed (X3), tofu dregs (X4), and labor (X5), were systematically selected based on the microeconomic theory of dairy production and strict ruminant nutritional requirements.

The number of lactating cows (X1) serves as the primary biological capital unit that determines the base production capacity of a farm. Feed inputs were disaggregated into three distinct categories to accurately capture their unique marginal contributions to milk yield (Thayaparan et al. 2023). Forage (X2) is biologically essential for stimulating rumen activity and maintaining milk fat synthesis, commercial concentrate (X3) provides the critical high-density protein and metabolizable energy required to push the production frontier, and tofu dregs (X4) act as a localized, cost-effective alternative protein source, which represents a crucial survival strategy for smallholders facing severe post-FMD economic constraints. Labor (X5) represents the human capital necessary for rigorous daily operations of herd management, feeding, and milking.

The stochastic frontier production function postulates a composed error term, . The component v_i represents symmetric, independently distributed random errors $N(0,\sigma^2_u)$ capturing exogenous shocks (such as the lingering effects of the FMD outbreak and climate variations), thereby satisfying the econometric validity constraints. The component u_i is a non-negative, truncated normal random variable $N(\mu,\sigma^2_u)$ that represents technical inefficiency. The Maximum Likelihood Estimation (MLE) method was employed to yield consistent, asymptotically efficient estimates for the parameter vector (β), variance parameters ($\sigma^2 = \sigma^2_v + \sigma^2_u$), and variance ratio ($\gamma = \sigma^2_u / \sigma^2$) (Aigner et al. 1977; Meeusen and van den Broeck, 1977; Jondrow et al. 1982).

$$LnY = LnA + \beta_1 LnX_1 + \beta_2 LnX_2 + \beta_3 LnX_3 + \beta_4 LnX_4 + \beta_5 LnX_5 + 1/2\beta_6 (LnX_{11})^2 + \ldots + \beta_{20} LnX_4 LnX_5 + (v_i - u_i)$$

Notes: Y (Yield (L/day)); A (Constant); β1–20 (Parameter); X1 (Number of lactating cows (head)); X2 (Forage (kg/day)); X3 (Number of concentrate feed (kg/day)); X4 (Number of tofu dregs (kg/day)); X5 (Labor (HOK/day))

The parameters β1–β20 are expected to be positive (βi>0), implying that farmers are operating within the rational stage of production. This implies that an increase in production factors can increase milk production under constant or increasing return to scale. The βij values are built from the interaction terms between production inputs, namely X1 with X1, X1 with X2, and X1 with X3, and so forth. The production function is then differentiated to determine the production elasticity (Ep) for each production factor using the following equation:

$$E_{PX_i} = \frac{\partial LnY}{\partial LnX_i} = \beta_i + \sum_{j=1}^{5} \beta_{ij} LnX_{ij}$$

The estimation of the translog production function in this study was performed using the Maximum Likelihood Estimation (MLE) method, which is commonly employed to estimate the parameters of a stochastic frontier model. MLE operates by maximizing the likelihood function based on the distributions of the random error (vi) and technical inefficiency (ui) to obtain simultaneous estimates of the parameters β, σv^2 and σu^2. Technical efficiency (TEi) was calculated using the ratio of actual output to potential frontier output, and the level of technical efficiency for the dairy farms was measured using the stochastic frontier approach. This method was chosen because it accounts for random errors in production, distinguishing between deviations caused by inefficiency and those attributable to external, uncontrollable factors. The production function utilized is the translog function, with the analysis stages encompassing the estimation of production parameters and the inefficiency function. The measure of technical efficiency was calculated based on the equation provided by Coelli et al. (2005).

$$TE_i = Y_i / Y_i^* = EXP(-U_i)$$

The technical efficiency (TE) value lies within the range $0 \leq TE \leq 1$. The closer the TE value approaches 1, the more technically efficient is the farm. Conversely, if the TE value approaches zero, the farm is considered inefficient. The inefficiency effects model is used to calculate the TE scores and to analyze the socioeconomic factors such as age, education, family dependents, participation in farmer groups, training or technical support, and credit access that influence technical inefficiency, adopting a specific equation within the stochastic frontier approach.

$$U_i = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 Z_3 + \delta_4 Z_4 + \delta_5 D_5 + \delta_6 D_6$$

The expected sign for the δ parameters (δ_1 – δ6) in the technical inefficiency function is negative ($\delta_i < 0$). A negative sign on an estimated coefficient indicates that an increase in the corresponding independent variable reduces technical inefficiency. Conversely, if the estimated coefficient is positive, an increase in the independent variable will result in a higher level of technical inefficiency.

Profitability is an important indicator for assessing farm performance in the Philippines. In this study, profitability analysis is divided into two types: profitability over cash costs and profitability over total costs. The goal is to evaluate whether the farm generates profit or incurs a loss. Total revenue includes cash revenue from milk sales during March and April 2025, as well as imputed revenue, such as milk used for calf feed or processed products. Revenue is obtained by multiplying the production volume by the market price. Meanwhile, the total cost consists of cash costs (feed, hired labor, vitamins, medicine, electricity, and water) and imputed costs (family labor and equipment depreciation). Profitability is calculated by subtracting costs from revenue, and is accompanied by the calculation of the revenue-cost() ratiotio) as an indicator of business feasibility. Through this approach, the analysis can identify the financial and economic efficiency of farm operations.

Total Profit = Total Revenue – Total Cost
Cash Profit = Total Revenue – Cash Cost

After calculating profitability, the next phase is to calculate the R/C ratio by dividing cash revenue by cash costs and total revenue by total costs. This is mathematically expressed as:

R/C for csh cost = Total Revenue/Cash Cost
R/C for total cost = Total Revenue/Total Cost

The interpretation criteria are as follows: if the R/C ratio > 1, the farm operation is considered profitable because revenue is greater than the costs. Conversely, if the R/C ratio is less than one, farm operations are unprofitable because revenue is less than costs. If the R/C ratio is 1, the farm earns a normal profit (break-even) and is still considered feasible to operate.

Based on production theory and previous empirical studies, this study proposes three main hypotheses regarding the dairy farms in KUNAK.

1. H1: Production inputs, specifically the number of lactating cows, concentrate feed, tofu dregs, and labor, have a significant positive effect on milk production. These statements are based on production theory, which suggests that rational increases in variable inputs within the productive stage (Stage II) will lead to increased output, as supported by the findings of Simamora and Zebua (2022).
2. H2: KUNAK dairy farmers operate at a technically efficient level. These statements are based on a specialized cluster (KUNAK); farmers are expected to have better access to knowledge and resources than independent farmers, potentially leading to TE scores > 0.7.
3. H3: The dairy farming business in KUNAK is profitable and feasible (R/C > 1). These statements are based on the existence of a cooperative market guarantee and the biological nature of dairy farming, which typically sustains a margin over operational costs, as experienced in similar studies by Priambodo (2024).

Figure 2 illustrates the systemic flow of the research, beginning with the identification of the core problem, which is the decline in milk production and population in KUNAK due to the FMD outbreak. The analysis breaks down the farming operation into technical components (production inputs such as feed and cows) and economic components (costs and revenue). These components are processed through three parallel analyses: SFA for production factors, technical efficiency measurement, and R/C ratio for profitability. The framework posits that technical inputs directly determine production volume and efficiency levels, while the interaction between market prices and input costs determines profitability. Ultimately, the synthesis of these three analyses led to comprehensive recommendations for improving farm resilience and welfare.

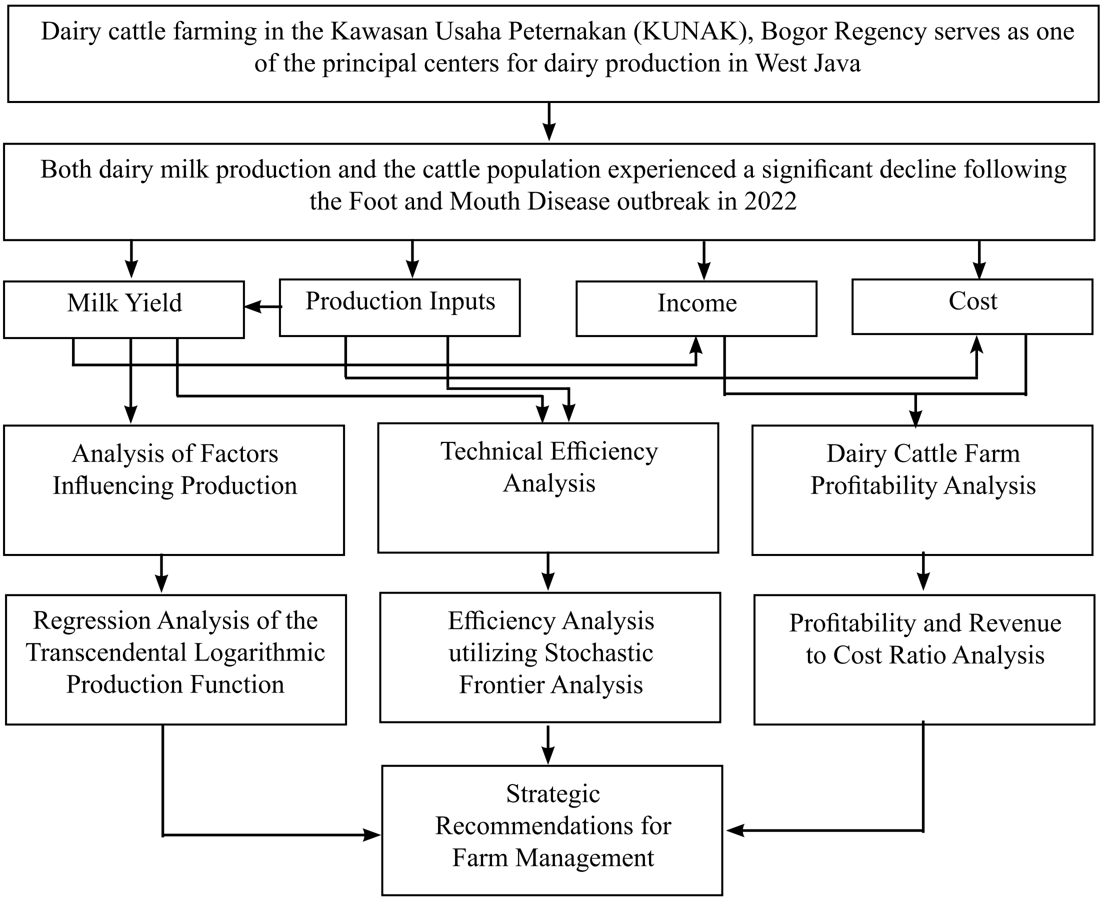

Figure 2. Research framework

RESULTS

Factors Affecting Dairy Farm Production

Dairy farmers in KUNAK optimize milk production using inputs such as the number of lactating cows (X1), forage (X2), concentrate feed (X3), tofu dregs (X4), and labor (X5), with milk volume (Y) as the dependent variable. The average production of 97.80 L/d or 9.17 L/cow/d remains below the Bogor Regency average of 12.83 L/cow/d reported by Famelika (2018) and the maximum potential for Friesian Holstein cattle, which is 14.75–18.03 L/cow/d (Ako, 2013).

The estimation using the translog production function model via the stochastic frontier approach and MLE methods is shown in Table 3. The results indicate a sigma-squared (σ^2) value of 0.1825 and a gamma (ɣ) value of 0.9334, which implies that 93,34% of the variation in output is attributable to technical inefficiency. The MLE log-likelihood value (23.4346) is higher than the OLS value (21.3117), and the LR test value (14.2455) exceeds the critical Chi-square value (11.6509) at the 5% significance level (Kodde and Palm, 1986). This demonstrates that the model is appropriate and effective for identifying the sources of production inefficiency.

Based on Tables 3 and 4, four input variables have a significant effect on milk production: the number of lactating cows, concentrate feed, tofu dregs, and labor. The number of lactating cows shows an elasticity of 0.6563, indicating a tendency towards decreasing returns to scale, as noted by Novitasari et al. (2023). Concentrate feed (0.1936) and tofu dregs (0.1594) both had a positive impact, although the effect of concentrate was limited due to the impact of FMD (Simamora and Zebua, 2022), and the use of tofu dregs must be balanced to avoid anti-nutritional factors (Waspodo, 2006).

The negative production elasticity of labor (-0.0830) indicates that the dairy farms are operating in the irrational stage of production (Stage III) in terms of workforce utilization. From a farm management economics perspective, this reflects severe labor redundancy and diminishing marginal returns. Unlike large-scale commercial operations, smallholder farms in KUNAK typically rely heavily on family members or informally hired local labor without strict time-allocation mechanisms. This overutilization leads to a marginal physical product of labor that is less than zero, suggesting that reallocating labor resources to alternative economic activities would paradoxically increase overall farm productivity and reduce the overhead costs.

This contradiction implies that while previous studies in similar regions found labor to be a productive driver, the current labor structure in KUNAK has reached a stage of diminishing returns that indicates severe overutilization. This statement aligns with Sudono et al. (2003), who asserted that labor efficiency in smallholder farms often exceeds the ideal ratio of 0.14 HOK/head/day. KUNAK farmers currently utilize 0.16 HOK/head/day, suggesting that reducing labor would increase the marginal productivity.

Table 3. Maximum likelihood estimates of the stochastic frontier translog production function for dairy farms in KUNAK (n=67)

Variable	Parameter	Coeff.	St. Dev	T-Ratio
Constant	β_0	4.4775**	1.1587	
X1	β_1	2.2368**	0.8192	3.8642
X2	β_2	0.4780	0.5370	2.7303
X3	β_3	-0.6574**	0.6414	0.8902
X4	β_4	-1.0072**	0.4501	-2.0250
X5	β_5	-1.5976**	0.6322	-2.2379
X1*X1	β_6	-0.0594	0.4605	-2.5273
X2*X2	β_7	-0.2430	0.1565	-0.1290
X3*X3	β_8	-0.0152	0.1466	-1.5520
X4*X4	β_9	0.2651**	0.1237	-0.1038
X5*X5	β_{10}	-0.2680	0.1771	2.1431
X1*X2	β_{11}	0.3446	0.2650	-1.5128
X1*X3	β_{12}	-0.2653	0.2666	1.3007
X1*X4	β_{13}	-0.4410**	0.1205	-0.9952
X1*X5	β_{14}	-0.0543	0.1522	-3.6584
X2*X3	β_{15}	0.0071	0.1440	-0.3567
X2*X4	β_{16}	-0.0051	0.0952	0.0490
X2*X5	β_{17}	0.1138	0.1184	-0.0539
X3*X4	β_{18}	0.1773	0.1118	0.9609
X3*X5	β_{19}	0.3130**	0.1223	1.5856
X4*X5	β_{20}	0.0462	0.0887	2.5586
Sigma-squared (σ2)		0.1825**	0.1013	3.8022
Gamma (ɣ)		0.9334**	0.0735	12.6962
Log-Likelihood MLE		23.4346		
Log-Likelihood OLS		21.3117		
LR-Test		14.2455		

**) Significant at α=5%

Table 4. Production elasticities of inputs derived from the translog function

Variable	Elasticity
Number of lactating cows (X1)	0.6563
Number of forage given (X2)	0.0387
Number of concentrate given (X3)	0.1936
Number of tofu dregs given (X4)	0.1594
Labor (X5)	-0.0830
Total	1.1614

Of the five input variables, only forage (X2) did not have a significant effect at the 5% significance level, despite having a production elasticity of 0.0387. A significant divergence was observed in the forage inputs. While Simamora and Zebua (2022), Priambodo (2024), and Karuniawati and Fariyanti (2017) consistently identified forage as a statistically significant determinant of milk yield, this study found forage to be insignificant. This lack of statistical significance may be attributed to the quality of forage available post-FMD or inefficient feeding practices specific to the KUNAK cluster during the study period. The total production elasticity (sum of elasticities) is 1.1614, indicating that the dairy farms in KUNAK are operating under increasing returns to scale. This implies that a 1% proportional increase in all inputs will increase the milk output by 1.16%. This finding aligns with Cabrera et al. (2010), who stated that a proportional increase in inputs yields a greater increase in output. Therefore, managerial efficiency and feed adequacy are key factors in increasing productivity.

Technical Efficiency and Inefficiency Factors

The technical efficiency of dairy farms explains the extent to which farmers can maximize their output from a given set of inputs. In this study, technical efficiency was estimated using the Stochastic Frontier Analysis (SFA) approach with a translog production function. According to Kumbhakar (2002), technical efficiency (TEi) is categorized into four levels: inefficient (TEi ≤ 0.70), low efficiency (0.70 < TEi ≤ 0.80), moderate efficiency (0.80 < TEi ≤ 0.90), and high efficiency 0.90 < TEi ≤ 1.00).

The estimation results in Table 5 show that the majority of farmers in KUNAK have achieved good technical efficiency, with 46.26% in the high-efficiency category and 38.80% in the moderate category. Only 14.94% are in the low-efficiency category, with three farmers classified as inefficient. The average TEi for the respondents was 0.8684, showing a relatively high level of technical efficiency overall. The TEi values ranged from 0.4469 to 0.9702, demonstrating variations among farmers. This stands in contrast to Utami et al. (2020) and Astuti et al. (2010), who showed significantly lower efficiency levels (an average of 0.64 technical efficiency level) in Tanjungsari and Kaliurang. This discrepancy indicates that KUNAK farmers have achieved superior mastery of technical inputs relative to farmers in those regions. Therefore, although most are efficient, continued technical support is important to improve the efficiency of farmers with low TEi scores.

Following the technical efficiency analysis, the factors influencing technical efficiency were identified by estimating the inefficiency effects model. The independent variables used in this model were the respondents' education level (Z1), age (Z2), number of family dependents (Z3), participation in a farmer group (D4), participation in training or technical support (D5), and access to credit (D6). The results of the inefficiency effects estimation are shown in Table 6. The estimation results for the technical inefficiency effects indicate that of the six variables tested, only two had a significant effect at the 5% significance level: farmer's age (Z2) and the number of family dependents (Z3). Farmer age (Z2) has a significant negative effect on technical inefficiency. This implies that as farmers age, their farm operations become more efficient, which is attributed to their increased experience and improved decision-making abilities. This finding is consistent with Cahyawati et al. (2014), who highlighted the role of experience in enhancing the efficiency of the work.

Table 5. Frequency Distribution of Technical Efficiency of Dairy Farms in (KUNAK) Bogor

Index Classification	Frequency	Percentage
TEi ≤ 0.70	3	4.49
0.70 < TEi ≤ 0.80	7	10.45
0.80 < TEi ≤ 0.90	26	38.80
0.90 < TEi ≤ 1.00	31	46.26
Total	67	100
Average	0.8684	
Maximum Value	0.9702	
Minimum Value	0.4469	

Table 6. Parameter estimates of the technical inefficiency effects model

Variable	Coeff.	T-Ratio
Constant	0.1017	0.10
Education level (Z1)	-0.0006	-0.78
Age (Z2)	-0.0297**	2.15
Family dependents (Z3)	0.0047**	-2.50
Participation in a farmer group (D4)	-0.0374	0.20
Participation in training or technical support (D5)	0.0072	-0.30
Credit access (D6)	-0.0109	0.80

The number of family dependents (Z3) has a significant positive effect on technical inefficiency. This indicates that a higher household consumption burden forces the diversion of critical financial resources away from productive farm investments (such as purchasing high-quality concentrates) and toward daily domestic needs. This empirical finding is strongly corroborated by recent stochastic frontier studies on smallholder dairy operations in developing nations, which demonstrate that larger family sizes consistently correlate with elevated technical inefficiency due to similar capital constraints and resource dilution (Rathnayake et al. 2023).

The number of family dependents (Z3) has a significant positive effect on technical inefficiency. This is attributed to the fact that a higher household consumption burden may divert resources from productive activities (Delfiyanti 2022). Meanwhile, the other four variables, education (Z1), farmer group participation (D4), training (D5), and access to credit (D6), were statistically insignificant, even though their coefficients had the theoretically expected signs. This result contradicts the findings of Santoso and Marzuki (2013) and Rachmawati and Kartiasih (2018), who established a strong bond between higher education levels and improved technical efficiency. The insignificance of education in KUNAK suggests that formal education levels may not directly affect better farm management skills in this specific community or that practical experience plays a far more critical role than formal schooling.

Education (Z1) showed a negative coefficient, implying that it tends to reduce inefficiency, but the effect was not statistically significant. Similarly, participation in a farmer group (D4) was insignificant, although it was theoretically expected to enhance efficiency through collaboration (Ulfa et al. 2020). Unexpectedly, training (D5) exhibited a positive correlation with inefficiency, possibly because the training provided was not relevant to local needs. Access to credit (D6) had the expected negative sign but was insignificant, potentially because most farmers depend on their own capital rather than external credit.

Farm Profitability

Profitability is a significant indicator of the success of dairy farming in KUNAK, reflecting the farmers' effectiveness in managing inputs to achieve economic incentives. This study estimated profitability based on the revenue structure (milk sales and internal consumption) and cost structure (cash and imputed), while also calculating the R/C ratio. Revenue was measured from the milk production volume per cow multiplied by the average selling price of IDR8,000/liter during March–April 2025. All farmers are members of KPS Bogor and are required to sell a minimum of 80% of their milk yield to the cooperative due to limited access to independent distribution channels. Table 7 presents the calculation results for farmer revenue in KUNAK, Bogor Regency.

The average revenue for dairy farmers in KUNAK reached IDR2,282,073.23 per head per month, which includes IDR74,873.45 in imputed revenue from milk allocated to calves. This figure is lower than that in Banyuwangi (IDR3,078,250 per head), primarily because the milk price at KPS Bogor (IDR8,018.66/liter) is lower than that at PESAT Banyuwangi (IDR10,000/liter) (Priambodo 2024). The total operational costs in KUNAK were recorded at IDR2,074,121.33 per head per month, comprising 85.38% cash costs and 14.62% imputed costs. Although these costs are lower than those in Banyuwangi (IDR2,477,935), the profit margin is also narrower due to the lower total revenue.

Table 8 indicates that feed cost is the largest component in the farm cost structure at KUNAK, totaling IDR1,603,386.79 per head per month or 77.31% of total costs. This supports the findings of Anindyasari et al. (2019), who reported the dominance of feed costs. The feed components consisted of concentrate (IDR719,872.75 or 34.71%), tofu dregs (IDR508,888.63 or 24.54%), and forage (IDR374,625.41 or 18.06%). Although concentrate prices are subsidized by the cooperative, some farmers opt for higher-quality feed from external sources. Tofu dregs have been used more intensively post-FMD, whereas forage is largely sourced from the farmers' own land but is managed inefficiently (Suroto and Murti, 2024).

Labor costs accounted for 16.12% of the total costs, comprising hired labor (TKLK) at IDR312,373.02 and family labor (TKDK) at IDR22,056.51. Hired labor (4.50 HOK) is more dominant than family labor (0.33 HOK), which differs from the pattern observed in Kebon Pedes (Malau and Winandi 2017). The high cost of labor is reflected in the hired labor wage of IDR69,451.75 per HOK, which is higher than that in Banyuwangi (IDR45.000,00) (Priambodo, 2024). To maintain livestock health, farmers have routinely administered vitamins and medicines since March 2025, costing IDR29,744.34 and IDR32,967.74 per head per month (2.70% of total costs), respectively. This practice has proven effective in increasing appetite and milk production (Agustina et al. 2020). Depreciation costs, which were estimated using the straight-line method, amounted to IDR18,859.16 per head per month (0.91%), with vehicle depreciation (IDR14,678.23) being the largest component. The profitability analysis indicates a profit over cash costs of Rp511,105.36 and a profit over total costs of IDR207,951.90 per head per month for the fattening period. The operation remains profitable, although the economic margin is small, which is aligned with the findings of Fauzan (2020) in Sleman.

Table 7. Dairy Cattle Farm Revenue Structure in KUNAK Bogor, Indonesia

	Volume (L/month)	Price (IDR)	Revenue (IDR/Month)	Revenue (IDR/head/month)
Revenue				
- Milk sales	2,837.91	8,018.66	22,756,229.67	2,207,199.77
- Milk for calves	96.27	8,018.66	771,945.31	`74,873.45
Total Revenue	2,934.18		23,528,174.98	2,282,073.23

Table 8. Dairy farm operational cost structure in KUNAK Bogor, Indonesia

	Cost (IDR/month)	Cost per head (IDR/head/month)	%
Cash Cost			
Concentrate	7,421,888.06	719,872.75	34.71
Tofu Dregs	5,246,641.79	508,888.63	24.54
Forage	1,158,716.40	112,387.62	5.42
Artificial Insemination	2,083.00	202.04	0.01
Vitamin	306,664.18	29,744.34	1.43
Drugs	271,917.91	26,374.19	1.27
Electricity cost	293,059.70	28,424.80	1.37
Water cost	47,923.08	4,648.21	0.22
Transportation cost	289,218.75	28,052.26	1.35
Hired labor cost	3,220,565.85	312,373.02	15.06
Total Cash Cost	18,258,678.70	1,770,967.87	85.38
Imputed Costs			
Depreciation cost	194,437.93	18,859.16	0.91
Family labor cost	227,402.66	22,056.51	1.06
Forage	2,703,671.59	262,237.79	12.64
Total Imputed Cost	3,125,512.18	303,153.46	14.62
Total Cost	21,384,190.90	2,074,121.33	100

Based on the measurements in Table 9, the average profit over the total costs received by farmers in KUNAK, at IDR2,542,295.06 per month, is still far below the Bogor Regency Minimum Wage (UMK) for 2025, which is IDR4,877,211. This shows that farmers' welfare has not yet been achieved in the study area. This short profitability is led by stagnating milk prices that are not proportional to the increase in production input costs, compounded by the impact of the FMD outbreak, which reduced production and increased the cost burden of dairy farming. This finding diverges sharply from Haloho et al. (2013), who reported a high profitability rate of 43.46% in Semarang, characterizing the business as highly lucrative. The contrast highlights the economic pressure currently faced by KUNAK farmers, likely driven by stagnant milk prices that have not kept pace with input inflation.

The R/C ratio over cash costs of 1.29 indicates that the operation is financially profitable because for every IDR1.00 in cash costs, it generates IDR1.29 in revenue. Meanwhile, the R/C ratio over total costs of 1.10 demonstrates that the operation remains economically feasible, although the margin is small. This result is in line with the findings of Malau and Winandi (2017), who recorded an R/C ratio of 1.25 at the same location. Thus, dairy farming in KUNAK remains feasible, even though it is not yet optimal for enhancing farmer welfare.

Managerial Implication

This study offers a critical theoretical contribution to the agricultural efficiency literature by demonstrating that high technical efficiency within an established cluster does not inherently guarantee economic welfare, particularly after structural shocks such as the FMD outbreak. While the operations in KUNAK demonstrate high technical mastery over available resources (average TE = 0.868), the empirical finding of a negative labor elasticity (-0.083) fundamentally challenges standard rational production assumptions. This reveals that severe resource constraints and structural market failures have driven smallholder operations into an irrational production stage (Stage III). Consequently, this study suggests that future stochastic frontier literature must deeply integrate institutional market analysis with technical efficiency metrics; measuring technical proficiency in isolation is inadequate for assessing true farm sustainability in developing economies.

The severe overutilization of manual labor and inefficiency driven by a high number of family dependents require immediate structural on-farm interventions. Rather than generic labor reductions, operations must transition back to a rational production stage through the strategic adoption of agricultural technologies. The implementation of milking machines and automated or semi-automated feeding systems is highly recommended. Such mechanization will directly address negative labor elasticity by reducing redundant manual work hours, optimizing the precise rationing of significant inputs such as concentrate and tofu dregs, and improving overall milk hygiene. Furthermore, to mitigate the inefficiency caused by family dependents, extension programs must provide targeted technical training. By converting family dependents into skilled operators of these modern farming tools, households can effectively substitute expensive hired labor with efficient family labor, directly expanding their constrained profit margins.

Table 9. Dairy farm profitability analysis (per head per month) in KUNAK) Bogor, Indonesia

	Components	Value
A	Total Revenue (IDR)	2,282,073.23
B	Cash Cost (IDR)	1,770,967.87
C	Imputed Cost (IDR)	303,153.46
D	Total Cost (B + C) (IDR)	2,074,121.33
E	Profit over cash costs (A – B) (IDR)	511,105.36
F	Profit over total costs (A – D) (IDR)	207,951.90
G	R/C over cash cost (A/B)	1.29
H	R/C over total cost (A/D)	1.10

At the institutional level, the stark disconnect between high production efficiency and marginal profitability signals systemic failure within the cluster's current operational model. Practical policy interventions must be enacted by the KPS Bogor and local agricultural authorities. Relying solely on arbitrary increases in milk prices is insufficient. Instead, cooperatives must establish subsidized, bulk-procurement supply chains for critical, highly elastic inputs, such as commercial concentrate feed. Additionally, policy frameworks should incentivize cooperatives to invest in value-added milk processing facilities. This strategic move would absorb the farmers' raw milk at competitive, inflation-adjusted prices, shielding smallholders from raw market volatility and restoring the economic agglomeration benefits that the KUNAK cluster was originally designed to provide.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This study contributes to the agricultural economics literature by providing empirical evidence that high technical efficiency within a government-supported cluster does not inherently guarantee economic sustainability, particularly in a post-shock environment (FMD recovery). Dairy farms in KUNAK operate with high technical efficiency (TE = 0.868) and increasing returns to scale, successfully optimizing available feed inputs such as concentrate and tofu dregs. However, the theoretical implication of negative labor elasticity reveals a structural flaw in smallholder resource allocation: a critical overutilization of labor that drives farms into an irrational production stage. Consequently, despite technical proficiency, profitability is severely marginalized by the disconnect between stagnant cooperative milk pricing and escalating input costs.

Recommendations

Farmers should increase the utilization of production factors that significantly and positively affect milk production, such as the number of lactating cows and the use of concentrate feed and tofu dregs. Furthermore, the use of forage and labor must be re-evaluated to enhance their efficiency. The cooperative is expected to increase the milk purchasing price and provide subsidies for production inputs to improve farm profitability. Additionally, the cooperative could provide training for farmers' family dependents, developing them into potential family labor (TKDK) to reduce costs.

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