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Determinants of Technical Efficiency in Beef Cattle Production in River Alluvial Areas near Hung Yen Urban Center

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Abstract

This study focused on estimating the level of technical efficiency in beef cattle production in the alluvial river areas near the Hung Yen urban center, using cross-sectional data collected from 150 beef cattle households. The data envelopment analysis was applied for technical efficiency estimation, and a Tobit modelling approach was employed to identify the determinants of technical efficiency. The results indicated that beef cattle production in the study area is characterized by a high and relatively homogeneous level of efficiency, with a mean technical efficiency under a variable return to scale of 95.4%. The key factors that positively enhanced technical efficiency included the farmer's education level, the proportion of household income derived from beef production, and the number of cattle sold. Dependence on purchased roughage and excessive warehouse area per head were found to significantly reduce efficiency. These findings suggest that competitiveness can be achieved by capitalizing on scale advantage through encouraging herd consolidation or moderate scale expansion. Furthermore, policies should promote on-farm forage development to reduce farmer reliance on unstable external feed markets, and extension programs should be strategically targeted towards technically oriented and educated farmers who show a higher capacity to adopt innovations.

Keywords

Beef cattle production, Data Envelopment Analysis, technical efficiency

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Introduction

The livestock sector plays an important role in Vietnam's agricultural economy by contributing to household income improvements and meeting the growing demand for animal-based food products (Figuié, 2006; Lam *et al.*, 2022; Pv, 2024). Beef consumption in Vietnam has increased steadily, with the average per capita consumption reaching 7.3kg per person annually during the 2018-2020 period. However, domestic production meets only about 45-50% of national demand, resulting in substantial imports of live cattle and beef products (Pv, 2024). While this growing demand creates opportunities for sectoral expansion, it also poses significant challenges related to productivity enhancement and product quality improvement in order to strengthen the competitiveness of domestic beef production (Hoang Kim Giao, 2018). Vietnam aims to maintain a stable beef cattle herd of approximately 6.5-6.6 million heads per annum (Vietnamese Prime Minister, 2020)

Despite its importance, Vietnam's beef cattle sector continues to face persistent structural constraints. Production remains largely small-scale and fragmented, resulting in low productivity, inconsistent product quality, and limited adoption of modern production technologies (Tran the Cuong *et al.*, 2021; Dinh *et al.*, 2024). Improving technical efficiency (TE) has been widely recognized as a key approach to addressing these challenges. According to Farrel (1957), TE reflects a producer's ability to maximize output from a given set of inputs without considering price effects. Measuring and analyzing TE, therefore, provides valuable insights into the effectiveness of resource utilization and enables the identification of key factors influencing production performance. Such analyses are essential for formulating strategies aimed at improving resource allocation and enhancing productivity in beef cattle production systems. In developing countries, identifying the factors associated with higher TE has been emphasized as a critical research priority (Nandy *et al.*, 2019).

Recent studies aimed at improving the performance of beef cattle production have largely focused on the development of beef value chains (Bui Van Quang & Nguyen Thi Duong Nga, 2020; Tran the Cuong *et al.* , 2021) and the characteristics of different production systems (Gioi *et al.*, 2022; Pham Van Hung *et al.*, 2022; Dinh *et al.*, 2024). These studies highlighted the importance of strengthening linkages among actors along the value chain that includes input suppliers, farmers, processors, and markets in order to enhance productivity and market access (Bui Van Quang & Nguyen Thi Duong Nga, 2020; Tran The Cuong *et al.*, 2021). In addition, researchers have examined various farming systems, such as grazing, semi-intensive, and stall-feeding models, identifying their roles in improving feed management, breed quality, and production outcomes (Gioi *et al.*, 2022; Pham Van Hung *et al.*, 2022; Dinh *et al.*, 2024). However, relatively limited attention has been given to evaluating the technical efficiency of beef cattle production at the farm level.

Former Hung Yen province maintains a beef cattle herd of approximately 27,499 heads, accounting for about 6.6% of the total herd in the Red River Delta region in 2023 (Vietnam Livestock Production, 2024). Old Hung Yen city ranks first in terms of total herd size, accounting for 49.1% of the provincial herd (30,483 heads) and contributing approximately 37.5% (equivalent to 1,634 tons) of the total live-weight beef output in 2023 (Hung Yen Statistics Office, 2024). Livestock production in the alluvial river region makes important contributions to livestock production of this region as a whole. Beef cattle production in particular, and livestock farming in general, in the alluvial river areas of Hung Yen Province have been developed with the objectives of promoting the adoption of safe livestock production practices in accordance with VietGAHP standards, targeting an adoption rate of 50-60%, and increasing the proportion of concentrated livestock production to 65-70% (Hung Yen Provincial Party Committee, 2022; People's Committee of Hung Yen Province, 2022). The province has identified beef cattle as a key component of its livestock development strategy, emphasizing genetic improvement, the application of scientific and technological innovations, and the efficient utilization of available feed resources (People's Committee of Hung Yen Province, 2022). Despite these strengths and opportunities, beef cattle production in the research site still faces major challenges, including small-scale operations and low value addition. Furthermore, competition from imported beef products continues to exert downward pressure on domestic producers, underscoring the need to enhance production efficiency and sustainability.

Given this context, the present study aimed to identify the level of technical efficiency in beef cattle production in the alluvial river areas near the Hung Yen urban center as well as its determinants. The results hope to provide empirical evidence to support the development of strategies that enhance productivity and optimize resource utilization of beef production, which can then contribute to improving farmers' income.

Methodology

Data

Primary data were obtained through a household survey of 150 beef cattle producers conducted in three old communes (Phu Cuong, Hung Cuong, and Tan Hung communes) located in the Red and Luoc alluvial river areas near the Hung Yen urban center (old Hung Yen city). These three communes represent the major beef cattle production areas, characterized by large herd sizes and a high level of production intensification.

The surveyed households were selected using a stratified random sampling approach based on official household lists provided by local veterinary and agricultural officers. Data collection was carried out between August and December 2024, resulting in a sample of 150 households in the three old communes.

Measurement of technical efficiency in beef cattle production by data envelopment analysis

TE is one of the two components of economic efficiency originally proposed by Farrel (1957) and it focuses on the relationship between inputs and outputs without considering prices, aiming to optimize the producer's resource allocation capacity to achieve the highest possible value or benefit under given market conditions. To measure it, data envelopment analysis (DEA), a non-parametric method that estimates the production frontier without requiring a specific functional form, was used, offering an alternative to the parametric stochastic frontier analysis approach (Coelli *et al.*, 2005). In this study, an input-oriented DEA model was adopted to assess how efficiently production inputs are utilized by beef cattle farmers, as some previous studies in livestock production have investigated how to save farmers' inputs while the farmers prefer to minimize changes in their output (Jabbar & Akter, 2008; Ly *et al.*, 2016, 2020; Le Thi Thu Huong & Luu Van Duy, 2022). Two models were estimated under different assumptions regarding returns to scale.

Model 1: Constant Returns to Scale

The first model assumed a constant returns to scale (CRS) to estimate the overall technical efficiency (TE_{crs}) as proposed by Charnes *et al.* (1978). The model is expressed as follows:

$$min_{\theta,\lambda}\theta, \quad (1)$$
$$Subject\ to\ -y_i + Y\lambda \geq 0,$$
$$\theta x_i - X\lambda \geq 0,$$
$$\lambda \geq 0$$

where x_i and y_i are the vectors of inputs and ouputs of beef producer i, respectively i = 1, 2…I; X and Y are the matrices of inputs and outputs of all beef producers; λ is a I * 1 vector of constants; and θ is the efficiency score and ranges from 0 to 1, where $\theta = 1$ indicates that the beef producer operates on the production frontier (fully technically efficient), while $\theta < 1$ implies technical inefficiency in production.

Model 2: Variable Returns to Scale

The second model assumed a variable returns to scale (VRS) to estimate the pure technical efficiency (TE_{vrs}) as developed by Banker *et al.* (1984). The model modifies the CRS formulation by adding a convexity constraint $1'\lambda = 1$, resulting in the following program:

$$min_{\theta,\lambda}\theta, \quad (2)$$
$$Subject\ to\ -y_i + Y\lambda \geq 0,$$
$$\theta x_i - X\lambda \geq 0,$$
$$I1'\ \lambda = 1$$
$$\lambda \geq 0$$

*in which I*1 is an I *1 vector of ones. This adjustment ensures that efficiency is estimated relative to firms operating under variable returns to scale, isolating the effects of scale from pure technical efficiency.

Scale efficiency (SE) measures the degree to which a beef cattle producer operates at an optimal scale and is calculated as follows:

$$SE = \frac{TE_{crs}}{TE_{vrs}} \quad (3)$$

If SE = 1 the beef producer operates at the point of constant returns to scale and is considered scale-efficient. If SE < 1, the beef cattle producer exhibits scale inefficiency, indicating that they could improve performance by adjusting their production scale.

In this study, all inputs and the output were calculated per head of beef cattle sold, consistent with prior studies in Vietnam (Gioi *et al.*, 2022; Pham Van Hung *et al.*, 2022). The nine input variables were: weight of calf (X_1, kg); labor (X_2, days); commercial concentrate feed (X_3, kg); agricultural concentrate feed (X_4, kg); roughage (X_5, 1,000VND); veterinary costs (X_6, 1,000 VND); fixed costs (X_7, 1,000VND); other costs (X_8, 1,000VND); and fattening time (X_9, months). The output variable represented the live weight gain of beef cattle sold (Y, kg head^{-1}). The selection of these variables was scientifically grounded in prior studies on beef cattle production systems, while also reflecting the specific characteristics of Vietnam's predominantly small-scale and dispersed farming structure. In particular, the inclusion of agricultural concentrate feed (X_4, kg); veterinary costs (X_6, 1,000 VND); and fattening time (X_9, months) accounted for the widespread use of locally available feeding resources, the heterogeneity in household-level management and animal health practices, and the common reliance on extended fattening periods to optimize growth under resource constraints, respectively. Detailed definitions and supporting references for each variable are provided in **Table 1**.

In addition, the sample size of 150 observations ensured sufficient degrees of freedom for the DEA model, as it substantially exceeded the threshold suggested by Cooper *et al.* (2007), where the number of units is at least three times the sum of the inputs and outputs.

The estimations of TE_{crs}, TE_{vrs} and SE were carried out using the software DEAP version 2.1 (Coelli, 1996).

Determinants of technical efficiency in beef cattle production by the Tobit model

Following the estimation of the TE scores from DEA, the Tobit regression model was employed to identify the factors affecting the TE of beef cattle producers. Since TE scores are censored between 0 and 1, the selection of the Tobit model was dictated by the censored nature of the efficiency data that was originally introduced by Tobin (1958), which treats the TE score as a latent variable. This Tobit model was utilized to overcome the limitations of traditional linear regression models, which fail to account for the truncated nature of the data. This two-stage approach, which has been widely applied by previous studies on TE determinants in livestock production (Ly *et al.*, 2016, 2020; Le Thi Thu Huong & Luu Van Duy, 2022; Radzil *et al.*, 2023; Xue *et al.* , 2024), allows for a rigorous assessment of how socio-economic and management factors drive efficiency. While acknowledging the potential for serial correlation in two-stage models (Simar & Wilson, 2007), the emphasis here was placed on identifying the consistent direction and significance of these determinants to provide actionable recommendations for smallholder farmers.

Moreover, the VRS assumption in the DEA step implies heterogeneous production scales across smallholder farmers, a condition typical in beef cattle systems in developing countries. Because VRS DEA produces a distribution of TE scores that frequently includes many fully efficient units (TE = 1) and avoids negative values, the resulting censored distribution reinforces the suitability of the Tobit model for second-stage analysis. By incorporating this censored distribution, the Tobit model provides consistent estimates of how farm characteristics, management practices, and resource endowments influence underlying efficiency. The Tobit model assumes a latent continuous variable TE^* that is observed only within a

Table 1. Inputs and output in beef cattle production to measure technical efficiency

Variable	Definition	Unit	Reference
Inputs			
Weight of calf (X1)	the live weight of the calf at the beginning of the fattening cycle	kg	Xue *et al*. (2024)
Labor (X2)	the total number of working days contributed by both household members and hired workers for feeding, cleaning, health care, and overall animal management	person-day	Alhas-Eroglu (2023; Xue *et al.* (2024)
Commercial concentrate feed (X3)	the quantity of industrially manufactured concentrate feed provided to the cattle	kg	Alhas-Eroglu (2023); Xue *et al.* (2024)
Agri_concentrate feed (X4)	farm-produced or locally sourced feedstuffs such as maize, rice bran, or by-products that supplement the animal's diet	kg	
Roughage (X5)	expenditures on fibrous feed materials such as grass, crop residues, and silage	1000 VND	Alhas-Eroglu (2023); Xue *et al.* (2024)
Veterinary costs (X6)	total spending on animal health care, including vaccines, medicines, deworming, and veterinary services	1000 VND	
Fixed costs (X7)	depreciation of cattle sheds, equipment, feeding facilities, and other capital items that do not vary with the number of cattle fattened	1000 VND	Alhas-Eroglu (2023; Xue *et al.* (2024)
Other costs (X8)	miscellaneous expenditures such as electricity, water, transportation, bedding materials, and other operational costs not classified elsewhere	1000 VND	Alhas-Eroglu (2023; Xue *et al.* (2024)
Fattening time (X9)	total duration of the fattening period from calf purchase to final sale	months	
Output			
Weight gain (Y)	the total increase in live weight during the fattening cycle, calculated as the difference between the sale weight and the initial weight of the calf	kg	Alhas-Eroglu (2023; Xue *et al.* (2024)

Note: 1000VND equivalent to 0.04USD.

restricted range. The empirical Tobit model with both right- and left-censored (Gujarati, 2011) is specified as:

$$TE_i^* = z_i\beta + u_i \quad (4)$$

with the observed variable TE_i given by

$$TE_i = \begin{cases} 0 \ if \ TE_i^* \leq 0 \\ TE_i^* \ if 0 < TE_i^* < 1 \\ 1 \ if \ otherwise \end{cases} \quad (5)$$

in which TE_i^* is the latent variable with TE_i representing TE_{vrs} for that observed dependent variable; z_i denotes the vector of the explanatory variables, including the various farmer and beef cattle farm characteristic factors defined in **Table 2**; β denotes the relationship between the latent and the explanatory variables; and u_i is the random error, normally distributed with mean zero and variance δ^2.

The explanatory variables (Z_j) included in the Tobit model captured the key managerial, household, and production characteristics that may influence TE in smallholder beef cattle systems. Manager attributes such as age (Z_1), gender (Z_2), education (Z_3), and experience (Z_4) reflected the decision-making capacity, knowledge, and production skills of farmers. The economic and resource conditions included the beef income proportion (Z_5) and grass area availability (Z_6), which indicated the farm's resource base and specialization. Production practices, including purchased roughage (Z_7) and warehouse area per head (Z_8), represented input quality and housing conditions. Training participation (Z_9) captured access to technical knowledge, while the number of cattle sold (Z_{10}) reflected production scale. Together, these variables encompassed the main factors expected to shape efficiency variations among households. The detailed definition and expected sign of these variables are shown in **Table 2**. The Tobit model was estimated using STATA software.

Table 2. Variables using in the Tobit model

Variable	Definition	Unit	Expected sign	Source
I. Dependent variable				
TEvrs (Y)	technical efficiency score under VRS measured by DEA model	%		
II. Independent variables				
Age (Z_1)	years of professionally fattening cattle of the main farm manager	years	+/-	(Pham Van Hung *et al.*, 2022; Alhas-Eroglu, 2023; Xue *et al.*, 2024)
Gender (Z_2)	= 1 if the main farm manager is male, = 0 if otherwise	1 = male	+	(Kalangi *et al.*, 2014)
Edu (Z_3)	number of schooling years of the main farm manager	years	+	(Kalangi *et al.*, 2014; Radzil *et al.*, 2023; Xue *et al.*, 2024)
Experience (Z_4)	duration of the farmer in cattle fattening activities	years	+	(Radzil *et al.*, 2023; Xue *et al.*, 2024)
Beef income proportion (Z_5)	proportion of household income contributed by beef production	%	+	(Kalangi *et al.*, 2014; Alhas-Eroglu, 2023)
Grass area (Z_6)	= 1 if the beef cattle farm grows grass, = 0 if otherwise	1 = having	-	(Alhas-Eroglu, 2023)
Purchased roughage (Z_7)	= 1 if the beef cattle farm bought roughage, = 0 if otherwise	1 = purchased	-	(Alhas-Eroglu, 2023)
Warehouse area per head (Z_8)	average warehouse area per cattle	m^2/head	-	(Xue *et al.*, 2024)
Training (Z9)	= 1 if the farm manager is trained in beef cattle production, = 0 if otherwise	1 = training	+	(Xue *et al.*, 2024)
No. cattle sold 2023 (Z_{10})	number of cattle sold in 2023	heads	+	(Alhas-Eroglu, 2023)

Results and Discussion

Beef production producers' characteristics in the alluvial river areas near Hung Yen urban center

The descriptive statistics for the input and output variables utilized in the beef cattle production are shown in **Table 3**. The results revealed a production system characterized by significant heterogeneity across the beef cattle households. Firstly, the average weight gain, as the primary output variable, was reported at 352.0kg per head, with a standard deviation of 55.5kg, indicating a moderate variation in production performance among households. On the input side, there were five input variables measured in physical units, while the rest were measured in values. For those measured in physical units, the feeding regime appeared to rely heavily on commercial concentrate feed, with a mean usage of 860.5kg, nearly double the quantity of agricultural by-product concentrates (469.9kg). This suggests a shift towards more intensive feeding practices in the study area.

The financial inputs exhibited a high degree of heterogeneity across the surveyed households, reflected in the substantial standard deviations relative to their respective means. This variability highlights diverse management strategies and investment levels within the study area. Notably, the expenditure on roughage showed a standard deviation (784.2 thousand VND ≈ 31.4 USD) that was nearly equivalent to its mean (931.2 thousand VND ≈ 37.2USD). This high dispersion was likely attributable to the structural differences in sourcing strategies, as indicated in the explanatory variables (**Table 4**), where only 60% of the households engaged in purchasing roughage. Consequently, the dataset captured a dichotomy between extensive farmers

Table 3. Descriptive results of the inputs and output of beef production

Variable	Unit	Mean	Std. Dev.	Min	Max
Inputs					
Weight of calf (X1)	kg	195.5	57.5	120.0	620.0
Labor (X2)	days	34.1	26.7	3.6	180.0
Commercial concentrate feed (X3)	kg	860.5	251.2	108.0	1350.0
Agri_concentrate feed (X4)	kg	469.9	257.6	0.0	1110.0
Roughage (X5)	1000VND	931.2	784.2	0.0	3076.9
Veterinary cost (X6)	1000VND	343.8	384.2	20.0	2200.0
Fixed cost (X7)	1000VND	931.1	734.1	280.6	5573.4
Other cost (X8)	1000VND	994.3	882.4	7.2	5350.0
Fattening time (X9)	months	12.3	1.9	1.0	16.0
Output					
Weight gain	kg	352.0	55.5	40.0	490.4

Source: Survey in 2024; n = 150.
Note: 1000VND equivalent to 0.04USD.

Table 4. Descriptive results of the variables explaining the technical efficiency in the Tobit model

Variable	Unit	Mean	Std. Dev	Min	Max
Age (Z_1)	years	53.9	10.2	28.0	73.0
Gender (Z_2)	1 = male	0.6	0.5	0.0	1.0
Edu (Z_3)	years	7.5	2.5	2.0	15.0
Experience (Z_4)	years	22.4	11.1	3.0	46.0
Beef income proportion (Z_5)	%	39.0	23.5	1.0	100.0
Grass area (Z_6)	1 = having	0.7	0.5	0.0	1.0
Purchased roughage (Z_7)	1 = bought	0.6	0.5	0.0	1.0
Warehouse area per head (Z_8)	m^2 $head^{-1}$	4.8	1.8	1.5	11.4
Training (Z_9)	1 = training	0.2	0.4	0.0	1.0
No. cattle sold 2023 (Z_{10})	heads	10.8	8.1	2.0	50.0

Source: Survey in 2024; n = 150.

utilizing free natural resources and intensive farmers reliant on purchased fodder.

Similarly, fixed costs and veterinary costs demonstrated significant variance, with standard deviations of 734.1 and 384.2 thousand VND (≈ 29.4 and 15.4USD), respectively. The variation in fixed costs mirrored the disparity in production scale, where the number of cattle sold ranged widely from 2 to 50 heads, necessitating different levels of infrastructure investment (**Table 4**). Meanwhile, the fluctuation in veterinary expenses suggests that disease management was not uniform, likely due to sporadic disease outbreaks or differing levels of preventative care adoption among the producers.

Furthermore, the socio-economic determinants and management characteristics hypothesized to influence TE are summarized in **Table 4**. The demographic profile showed an aging workforce with substantial practical experience but limited formal education. The average farmer was 53.9 years old with 22.4

years of experience in cattle rearing, yet the average duration of schooling was only 7.5 years. This creates a specific context where traditional knowledge may dominate over modern technical adoption. In addition, young laborers in the region seem to be increasingly unwilling to engage in cattle raising and farming.

Regarding economic perspective, beef cattle production accounted for an average of 39.0% of the total household income. The scale of commercialization was relatively modest, with an average of 10.8 cattle sold in 2023. Institutional and management variables highlight potential constraints in the sector. Notably, only 20% of the surveyed farmers have participated in technical training, suggesting a gap in extension services. Furthermore, reliance on external markets for roughage was high, with 60% of households reporting that they purchased roughage rather than producing it entirely on-farm. The housing conditions varied, with an average warehouse area of 4.8m^2 per head, ranging from 1.5 to 11.4m^2, which may have implications for animal welfare and disease management.

Level of technical efficiency of beef production

Table 5 presents the frequency distribution and summary statistics of the TE scores estimated under the assumption of CRS, VRS, and the resulting SE. The results indicated that beef cattle production in the alluvial river areas near the Hung Yen urban center is characterized by a relatively high level of TE.

Firstly, the mean TEvrs specification was 95.4%, which was notably higher than the mean TEcrs (92.0%). This discrepancy suggests that when the restrictive assumption of constant returns to scale is relaxed, the true managerial performance of the farmers is revealed to be superior. The high SE score (96.4%) further indicated that the majority of farmers are operating close to their optimal scale size, suggesting that scale is not a primary constraint to efficiency in this region. Economically, a mean TEvrs of 0.954 implies that, on average, the sampled households are realizing 95.4% of their potential output given their current input levels. This suggests that the sampled producers have successfully optimized their input-output ratios relative to the local production frontier, leaving limited room (approximately 4.6%) for improvement under current technological conditions.

In terms of the decomposition of inefficiency, comparing the three efficiency measures allows for the determination of the decomposition of total inefficiency. Since TEcrs (92.0%) was lower than both TEvrs (95.4%) and SE (96.4%), the overall technical inefficiency (8.0%) comprised both the pure technical inefficiency (4.6%) and scale inefficiency (3.6%). However, given that both the pure technical and scale efficiency scores were high, the remaining inefficiencies were likely attributable to subtle variations in input quality or specific managerial decisions rather than systemic structural failures.

Regarding to the distribution of the efficiency score, the results revealed a strong clustering of households at or near the efficiency frontier. Under the VRS model, nearly half of the respondents (47.3%, n = 71) were fully efficient (TE = 1.00), defining the "best practice" frontier for the region. Furthermore, a substantial majority (80%) of households achieved efficiency scores from 90% to 100%. The minimal presence of low-performing beef cattle households is noteworthy. No households recorded a TEvrs below 70%, and the minimum recorded score was 78.4%. This narrow range of efficiency scores from 78.4% to 100% points to a high degree of homogeneity in production techniques and management practices among the farmers in the region. In this study area, beef cattle production is primarily based on stall-feeding systems with farmers raising high-quality crossbred cattle with exotic bloodlines to improve meat quality (Vi Ngoan, 2025), such as the widespread adoption of specific crossbred beef (BBB) (Huyen Trang, 2017). Also, feed resources are actively managed through the utilization of agricultural by-products processed into nutrient-rich rations (Vi Ngoan, 2025). Local authorities support the sector by providing technical training, promoting breed improvement and the selection of quality foundation cows, and facilitating linkages between farmers and processing and marketing actors. This implies that knowledge spillover or standardized farming

Table 5. Frequency distributions of technical efficiency score under CRS, VRS, and scale efficiency scores

Efficiency scores	TEcrs		TEvrs		SE	
	No. of households	% of households	No. of households	% of households	No. of households	% of households
< 70%	1	0.7	0	0.0	0	0.0
70-80%	13	8.7	3	2.0	2	1.3
80-90%	44	29.3	27	18.0	15	10.0
90-100%	39	26.0	49	32.7	76	50.7
100%	53	35.3	71	47.3	57	38.0
Mean	92.0		95.4		96.4	
Std. Dev	8.3		5.9		5.1	
Min	66.3		78.4		71.7	
Max	100.0		100.0		100.0	

Source: Survey in 2024; n = 150.

practices may be prevalent in the community, which contrasts with several studies in developing contexts. For instance, Radzil *et al.* (2023) reported that only 28.74% of beef cattle farms in Peninsular Malaysia operated at full efficiency, with a significant portion scoring below 0.50. Similarly, Kalangi *et al.* (2014) observed lower mean efficiency scores in East Java of Indonesia, ranging from 64% in upland areas to 80% in lowland areas. However, the high efficiency observed in the region aligns with the meta-analysis by Nandy *et al.* (2019), which noted that 59% of reviewed studies reported efficiency scores in the 80-100% range, particularly in specific sub-sectors of livestock farming.

Determinants of technical efficiency of beef production

The results of the Tobit regression analysis identifying the exogenous factors influencing TE under VRS of beef cattle households are shown in **Table 6**. The likelihood ratio (LR) chi-square statistic of 33.130 was statistically significant at the 1% level, confirming that the explanatory variables jointly explained the variation in the efficiency scores. Gujarati (2011) pointed out that the magnitude of Tobit coefficients does not directly represent marginal effects, and their signs indicate the direction of the relationship between the determinants and efficiency. The analysis revealed that education, beef income proportion, and the number of cattle sold acted as efficiency drivers, whereas reliance on purchased roughage and warehouse area per head correlated with lower efficiency.

Firstly, among the demographic characteristics, education level (Z_3) exhibited a positive and significant impact on technical efficiency (estimated coefficient = 0.007 and P <0.05). This suggests that farmers with higher formal education are better equipped to adopt new technologies, manage input allocations, and optimize feeding regimes. Interestingly, experience (Z_4) and age (Z_1) were found to be statistically insignificant. This implies that in the context of the study site, accumulated traditional experience does not necessarily translate into higher efficiency, possibly because modern beef fattening techniques require updated technical knowledge rather than traditional husbandry practices. This contrasts with the findings of Radzil *et al.* (2023) in Malaysia, where experience was identified as a primary driver of TE. However, this result is consistent with the nuanced analysis by Xue *et al.* (2024), who argued that in the context of modernizing agriculture, traditional experience might entrench outdated methods, whereas formal education facilitates the adoption of modern husbandry techniques and management concepts. As Gioi *et al.* (2022) highlighted, the beef sector in Vietnam is shifting towards high-yield crossbred cattle (BBB, Brahman) and intensive feeding regimes. Managing these new

Table 6. Determinants of technical efficiency in beef production

Variables	Coef.		Std. Err	t	P > |t|	[95% Conf. Interval]	
Age (Z_1)	0.001		0.001	0.800	0.422	-0.001	0.003
Gender (Z_2)	-0.018		0.018	-1.030	0.306	-0.053	0.017
Edu (Z_3)	0.007	**	0.004	2.050	0.042	0.000	0.014
Experience (Z_4)	-0.001		0.001	-0.700	0.482	-0.002	0.001
Beef income proportion (Z_5)	0.001	**	0.000	2.610	0.010	0.000	0.002
Grass area (Z_6)	-0.011		0.018	-0.600	0.551	-0.046	0.025
Purchased roughage (Z_7)	-0.039	**	0.018	-2.160	0.032	-0.075	-0.003
Warehouse area per head (Z_8)	-0.010	**	0.005	-2.220	0.028	-0.019	-0.001
Training (Z_9)	-0.033		0.021	-1.520	0.130	-0.075	0.010
No. cattle sold 2023 (Z_{10})	0.004	***	0.001	2.970	0.003	0.001	0.007
Constant	0.918	***	0.064	14.290	0.000	0.791	1.045
var(e.vrste)	0.008		0.001			0.005	0.011
LR chi-squared (10)	33.130	***					
Log-likelihood	34.912						

Source: Survey in 2024; n = 150.

*Note: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.*

breeds requires the ability to understand complex nutritional and veterinary information, a skill set more closely correlated with formal schooling than with years of traditional grazing experience.

Similarly, the proportion of beef income (Z_5) was positively correlated with efficiency (coef. = 0.001, P <0.05). Households that specialize in cattle rearing (where beef is a primary income source) tend to invest more effort and management care into the herd compared to those treating it as a secondary side-line activity. This aligns with Alhas-Eroglu (2023) who found that specialized cattle farms (mean TE = 0.66) were technically more efficient than combined crop-livestock farms (mean TE = 0.55), as specialization allows for focused managerial attention and rational resource planning. In the region, households that rely on beef as a primary income source are likely transitioning from traditional husbandry to professional farming, thereby reducing inefficiencies.

Regarding input management, the variable purchased roughage (Z_7) had a significant negative coefficient (coef. = -0.039, P <0.05). This finding indicates that households relying on purchasing fodder from external markets are technically less efficient than those utilizing self-cultivated resources. This inefficiency can be attributed to higher transaction costs, transportation expenses, and the inconsistent quality of purchased feed, which disrupts the optimal input-output ratio. Moreover, the variable grass area (Z_6) also showed a negative coefficient (coef. = -0.020), although statistically insignificant. This counter-intuitive result suggests that merely possessing land for fodder is insufficient, as the efficiency of forage cultivation is critical. As Alhas-Eroglu (2023) argued, larger fodder crop areas can sometimes correlate with lower efficiency if they lead to a lack of specialization or if the management of crop-livestock integration is suboptimal. Conversely, Kalangi *et al.* (2014) emphasized that while the local grass availability is a dominant contributor to productivity, the distinct efficiency advantage lies with farmers who can effectively manage these resources. In the study area, the negative signs for both the purchased and self-grown roughage variables imply a dual challenge: farmers face market risks when buying feed but also lack the advanced agronomical skills or high-yield grass varieties to maximize the efficiency of their own land. Therefore, policy support should focus critically on enhancing the farmers' skills in intensive forage cultivation and preservation to reduce the reliance on unstable external markets.

Additionally, warehouse area per head (Z_8) showed a negative correlation with efficiency at the 5% significance level (coef. = -0.010). This implies that investing in excessively large barns relative to the herd size results in a waste of capital resources (higher depreciation and maintenance) without contributing proportionally to weight gain, thereby reducing TEvrs. This mirrors the observations by Xue *et al.* (2024) regarding small-scale farms, where suboptimal asset allocation often hampers cost efficiency. Excessive investment in housing infrastructure relative to herd size represents a "sunk cost" that does not translate into proportional weight gain, thereby depressing the marginal productivity of capital. In the larger context, enhancing welfare of animals represented by a large barn may conflict with the economic benefits of farm households. Therefore, a trade-off between the two objectives should be considered.

Another observation is that the training variable (Z_9) was negatively correlated with TEvrs (coef. = -0.033), although this effect was not statistically significant. This lack of significance suggests that, while training may be expected to enhance TEvrs, the current state of training participation does not yet demonstrably translate into measurable efficiency gains across the study area. The non-significant outcome for training contrasts with the expectation that targeted training can improve efficiency. Along with the result of education (Z_3), which measured the farmer's inherent ability to absorb information. This implies that while formal schooling aids management, the effectiveness of the training programs (Z_9) currently provided might be limited or the content may not be adequately focused on modern beef fattening techniques required for efficiency gains.

The results also provided strong empirical evidence for economies of scale. The number of cattle sold (Z10) variable showed a highly significant positive coefficient (coef. = 0.004, P <0.01). This indicates that larger commercial operations achieved higher efficiency scores, likely due to better resource utilization and the ability to spread fixed costs over a larger output volume. This agrees with the findings of Xue et al. (2024) in China, who demonstrated that large-scale farms consistently outperform small- and medium-scale operations in TEvrs due to superior bargaining power in factor markets and standardized management. Similarly, Alhas-Eroglu (2023) found that herd size significantly reduces technical inefficiency in Turkish beef farming.

Conclusions and Implications

As rising incomes and dietary shifts continue to increase domestic demand for beef in Vietnam, the sector remains predominantly dependent on smallholder systems characterized by fragmented production and comparatively low productivity. The study site in Hung Yen province exemplifies an intensive smallholder-based beef production area, yet empirical studies on technical efficiency in Vietnamese beef cattle systems remain limited. This study therefore contributes by examining the determinants of TE under smallholder intensive conditions.

The findings revealed that TE is generally high and relatively homogeneous across households, with an average TEvrs of 95.4% and 71 out of 150 households achieving full efficiency. Key factors enhancing TE included the farmer's education level, the share of income derived from beef production, and the number of cattle sold. Conversely, dependence on purchased roughage and larger warehouse area per head significantly reduced efficiency.

Based on these results, several policy implications emerge. First, encouraging herd consolidation or moderate scale expansion may improve performance, reflecting clear scale advantages. Second, given the negative effect of purchased roughage, policies should promote on-farm forage development and high-yield varieties to reduce reliance on unstable external feed markets. Finally, extension programs should target technically oriented and educated farmers who demonstrate a higher capacity to adopt innovations, thereby strengthening the transition toward more intensive and efficient beef production systems in Vietnam.

Despite the significant findings, this study acknowledges certain limitations that can be considered for future research. The current analysis was conducted in a region characterized by a relatively well-developed beef cattle sector; therefore, the results regarding technical efficiency levels and their determinants might not be fully representative of regions with different socio-economic profiles or lower levels of livestock intensification. To enhance the generalizability of the findings, future studies should consider a comparative analysis across various geographical areas with diverse levels of livestock intensification. Such a forward-looking approach would allow for a more nuanced and comprehensive understanding of the factors driving efficiency, enabling the formulation of broader agricultural policies that cater to the heterogeneity of smallholder farming systems in Vietnam.

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