AGRICULTURAL SCIENCE AND TECHNOLOGY, VOL. 12, No 1, pp 24-30, 2020
Published by Faculty of Agriculture, Trakia University, Bulgaria
ISSN 1313-8820 (print)
ISSN 1314-412X (online)
http://www.agriscitech.eu
DOI: 10.15547/ast.2020.01.005

Estimation of technical efficiency of cattle feedlot system in Adamawa State, Nigeria: Comparison among estimators

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(Manuscript received 22 September 2019; accepted for publication 10 January 2020)

Abstract. *This study adopts an output oriented Shephard Distance Function (SDF) to estimate Technical Efficiency (TE) in cattle feedlot under five distinct estimators (Data Envelopment Analysis /DEA/, Free Disposal Hull /FDH/, Order-m, Order-α and Bootstrap). The aim is to rank the efficiency estimates based on descending order of the TE estimates from the five estimators and test the hypotheses of mean difference across the estimators. In addition, the independent variables used in the feedlot system were also ranked based on magnitude to total cost. Results show initial cost of animal, feed cost, water cost, labour cost, depreciation, medicaments and cost of salt lick are ranked 1st, 2nd, 3rd, 4th, 5th, 6th and 7th, respectively, in terms of proportion to total cost. The study found a combination of inappropriate scale of production and managerial problems as the causes of inefficiency in the cattle feedlot. The study advocates for proper pricing of inputs, commensurate and timely utilization of inputs to avert input waste. Similarly, the study recommends up-scaling (178 cattle feedlot) and down-scaling (92 cattle feedlot) the cattle feedlot production owing to their operation at increasing and decreasing returns to scale, respectively, to attain enhanced efficiency.*

Keywords: cattle, cost, shephard distance function, data envelopment analysis, free disposal hull, order-m, order-α,

Introduction

Beef cattle is globally recognized as an important livestock sub-sector. Feedlot system of livestock production is the major source of beef in Czech Republic and most other nations in the European Union (Syrucek et al., 2017). It accounts for the majority of protein demand emanating from the ruminant sub-sector. Global beef production (dressed carcass weight) hit 64 million tons in 2013; accounting for per capita consumption of 8.9kg per year (FAOSTAT, 2015). The feedlot system and the cow-calf system are the two most famous intensive systems of livestock management in the tropics. The feedlot system as opposed to the cow-calf system of cattle management ensures optimum weight gain shortly before slaughter. This rapid weight gain adds to the lucrative status of the bull. The feedlot system of management serves as a window for additional quantum of protein requirement, source of employment via labour supply and additional demand owing to input supply and increase in revenue derive with resultant positive effect on the welfare of the cattle feedlot farmers. In view of its importance, World Bank (2004) vowed to ensure increased commitment to the livestock sector in relation to improved access to productive breed, veterinary services, input supply, credit facilities, access to technology, capacity building and access to competitive markets. IFAD, Danida and World Bank (2004) viewed small scale livestock farming as a window for poverty alleviation particularly in developing economies. Also, it doubles as collateral to secure credit facilities to expand the agricultural fortunes of farmers.

Cattle feedlot is one of the panacea for meeting the growing demand in human population due to increased protein requirement. Income per head is indirectly determined by resource use efficiency; which is further predicted by the disposable price (Kvapilik, 2008) and input cost (Norton, 2005). One of the major determinants of profitability in the cattle feedlot system is the live weight gain (Wolfova et al., 2004; Topcu and Uzundumlu, 2009). Additionally, Garip et al. (2010) remarked that increase in daily weight gain reduces days on feed and consequently the overall profitability of the cattle feedlot system. Beef production like any other agricultural enterprise must show evidence of profitable indicators, among others, to be termed sustainable. Several approaches abound for testing such indicators. Similarly, Ruiz et al. (2000) asserted that aiming maximum weight gain increases cost of production but equally results in increase in output which leads to increased profitability and subsequent increase in efficiency. However, Belasco et al. (2009) noted that the cattle feedlot production may sometimes be risky yielding wide range profitable indicators; oscillating between low and high losses. This study wields on the technical

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efficiency of cattle feedlot as a foundation for such indicators. Thus, efficient utilization of resources must be attained either as a condition for achieving profitability or an avenue for improving on existing profit level. In view of the significance of efficiency analyses in agriculture, this study therefore, seeks to compare between five different estimators or methodologies to measure technical efficiency in cattle feedlot in Adamawa State, Nigeria.

Material and methods

Study area

Adamawa State is in the North-Eastern part of Nigeria; located between latitude 7° and 11° North of the Equator and longitude 11° and 14° East of the Greenwich Meridian; covering 39742.12 km^2 in land (Adebayo and Tukur, 1999). It is a border state with Republic of Cameroun to the East, Borno State to the North, Gombe State to the North-West and Taraba State to the South and West. The State has total population of 3178959 as at 2006 NPC (2006); given 2.94% growth rate, thus for year 20 the projected population is 4633160 inhabitants. The State is agrarian in nature; featuring wide range agricultural activities. The State is highly known for livestock production due to prevalence of large number of inhabitants from the Fulani ethnic group who are traditionally known as livestock farmers. In addition, the availability of wide ranging pastures and water resources also promotes livestock production in the State. Nomadic herding has been the dominant system of managing livestock in the State, but with the current trend of farmer-herder clashes, sedentary system of livestock management is highly sought.

Sampling and data collection

The study utilizes multi-stage sampling technique in its data collection. In stage 1, purposive sampling method was used to select one Local Government Area (LGA) each from the four agricultural zones out of the 21 LGA in the state based on availability of cattle market with the highest intensity; areas with high market intensity often practice high cattle feedlot activities. The selection of a LGA each from the four zones was to provide representative and heterogenous samples across the State. The four LGA selected include: Mubi south, Song, Yola South and Ganye. The next stage involved selection of one district each with the highest feedlot activities. Three wards each were further selected purposely based on availability of the highest registered feedlot farms in each district as the next stage. In the final stage, 50% of the feedlot farms were drawn from each ward based on sampling frame of the registered farms. Thus, from a sampling frame of 535 registered farms, 270 (50%) feedlot units were randomly selected in the final stage for this study. See Figure 1 for details.

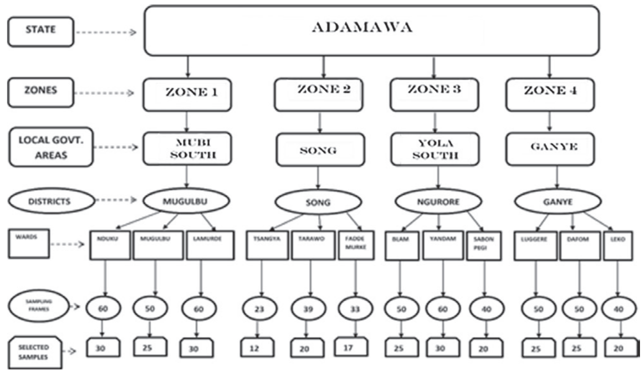

Figure 1. Levels of multi-stage sampling adopted during data collection

Analytical methods

The study used five estimators (DEA, Bootstrap, FDH, Order-m and Order-α) of technical efficiency (TE) to evaluate the efficiency situation in cattle feedlot system in Adamawa State, Nigeria.

Data envelopment analysis (DEA) estimator

Given sample of n observations (x_i, y_i) termed reference set {(x_i, y_i) | i = 1, …, n}. Shephard (1970) modelled the DEA estimator as:

$$\Psi_{DEA} = \{(x, y) \varepsilon R_+^{p+q} \mid y \leq \sum_{i=1}^{n} \gamma_i y_i;\ x \geq \sum_{i=1}^{n} \gamma_i x_i, \text{ for } (\gamma_1, \ldots, \gamma_n) \text{s.t} \sum_{i=1}^{n} \gamma_i = 1; \geq 0,\ i = 1, \ldots, n\}$$

Thus, the estimated output oriented DEA efficiency score of given DMU(x, y) is as below:

$$\lambda_{DEA} = \text{Max}\ \{\lambda \mid (x, \lambda y)\ \varepsilon\ \Psi_{DEA}\}$$

Free disposal hull (FDH) estimator

The FDH estimator is modelled in line with Deprins, Simar and Tulkens (1984) as below:

$$\Psi_{FDH} = \{(x, y) \varepsilon R_+^{p+q} \mid y \leq y_i,\ x \geq x_i,\ i = 1, \ldots, n\}$$

The output-oriented FDH is modelled below:

$$\lambda_{FDH} = \text{Max}\ \{\lambda \mid (x, \lambda y)\ \varepsilon\ \Psi_{FDH}\}$$

Both DEA and FDH are traditional non-parametric in nature as such they possess the following advantages; non-functional form specification, flexible for multi-input and multi-output analyses and estimations are based on efficient Decision Making Units (DMUs). However, the major drawback of these models is their sensitivity to outliers in the data set (Daraio and Simar, 2007). This limitation is a source of concern, hence the need for robust partial frontiers to overcome the drawback. Thus, Order-α and Order-m improves are introduced to improve on the shortcomings of the traditional non-parametric estimators.

Order-m estimator

This model is a generalization of the FDH via additional layer of randomness to the computation of efficiency score. Under this estimation, the DMU's are benchmarked based on expected best performance rather than best performing peer in the sample. In line with Daraio and Simar (2007), the model is shown below:

$$\Theta^{OM}_{mi} = 1/D \sum_{d=1}^{D} \theta^{FDH}{}_{mi}{}^{d}$$

Where θ^{OM}_{mi} is the Order-m efficiency score and $\theta^{FDH}{}_{mi}{}^{d}$ is the pseudo FDH efficiency calculated using artificial reference sample and D, the number of iterations.

Order-α estimator

This is another generalization to FDH estimation. Here, it uses percentile rather than best performing peers in the sample. Tauchmann (2011) showed that the Order-α estimator can be modelled as below:

$$\Theta_{\downarrow} ai^{\uparrow} OA = P_{\downarrow} \left(_{\downarrow} j\varepsilon Bi^{\uparrow} \left((100\text{-}a)\right)\left(\left(_{\downarrow} k = 1, \ldots, k^{\uparrow}\max\right) \{x_{\downarrow} kj / x_{\downarrow} ki\} \right)\right)$$

Where θ^{OA}_{ai} is Order-α efficiency score, α is the tuning parameter. When α=100, Order-α equates with FDH in magnitude. These non-parametric robust estimators are robust to outliers and noise. The data set and degree of robustness is adjusted by a tuning factor m, in the case of Order-m and α in the case of Order-α.

DEA-bootstrap

The bootstrap estimator is robust estimator for computing efficiency. It is an improvement over the conventional DEA estimator (Simar and Wilson, 2000); lacking in statistical content culminating into spurious and biased estimates (Vu, 2010). In line with Simar and Wilson (1998), the bootstrap estimator is computed with the aid of the equation below:

$$\Theta^{*}_{k,b} = \min \{ \Theta > 0 \mid y_k \le \sum_{i=1}^{n} (\gamma_i y_i \mid \Theta x_k \ge \sum_{i=1}^{n} (\gamma_i x_i^{*}, b \mid \sum_{i=1}^{n} \gamma_i = 1,$$
$$\gamma_i \ge 0, i = 1, \ldots, n)\}$$

Where $\Theta^{*}_{k,b}$ = bootstrap estimate, x_k = input data, y_k = output data, b = number of bootstrap iterations; minimum acceptable bootstrap iteration = 2000 (Simar and Wilson, 1998).

Formulated hypotheses

Table 1 presents a set of null hypotheses formulated to compare the mean TE estimated across the five estimators (DEA, Bootstrap, FDH, Order-α and Order-m) used in the study. The study adopts the Students-T test used to evaluate the hypotheses. The probability (p-values) of the hypotheses are presented in Table 6 of this study.

Table 1. Null hypotheses formulated for comparison of mean technical efficiency (TE) estimates based on the five estimators

Null hypotheses	Description of hypotheses
H_O: $TE_{FDH} \neq TE_{ORDER\text{-}m}$	No difference in mean TE estimates between FDH and ORDER-m estimators
H_O: $TE_{FDH} \neq TE_{ORDER\text{-}\alpha}$	No difference in mean TE estimates between FDH and ORDER-α estimators
H_O: $TE_{FDH} \neq TE_{DEA}$	No difference in mean TE estimates between FDH and DEA estimators
H_O: $TE_{FDH} \neq TE_{BOOTSTRAP}$	No difference in mean TE estimates between FDH and BOOTSTRAP estimators
H_O: $TE_{ORDER\text{-}m} \neq TE_{ORDER\text{-}\alpha}$	No difference in mean TE estimates between ORDER-M and ORDER-α estimators
H_O: $TE_{ORDER\text{-}m} \neq TE_{DEA}$	No difference in mean TE estimates between ORDER-m and DEA estimators
H_O: $TE_{ORDER\text{-}m} \neq TE_{BOOTSTRAP}$	No difference in mean TE estimates between ORDER-m and BOOTSTRAP estimators
H_O: $TE_{ORDER\text{-}\alpha} \neq TE_{DEA}$	No difference in mean TE estimates between ORDER-α and DEA estimators
H_O: $TE_{ORDER\text{-}\alpha} \neq TE_{BOOTSTRAP}$	No difference in mean TE estimates between ORDER-α and BOOTSTRAP estimators
H_O: $TE_{DEA} \neq TE_{BOOTSTRAP}$	No difference in mean TE estimates between DEA and BOOTSTRAP estimators

*FDH- Free Disposal Hull; DEA- Data Envelopment Analysis

Results and discussion

Table 2 shows the descriptive statistics of variables used in evaluating the technical efficiency in the cattle feedlot system of Adamawa State. It constitutes only one output (revenue) and seven inputs (initial cost, feed cost, labor cost, medicaments, water cost, depreciation and cost of salt) as variables. Summary in the table shows the cattle feedlot farmers generate revenue in the range of ₦90000 and ₦131000 and on average, a mean of ₦119056. A high standard deviation indicates wide variation in the revenue profile of the farmers. On the other hand, ranking of input variables shows mean cost of animal (₦68830) constitutes about 84% of cost production in the cattle feedlot systems and thus, ranked the 1st most important variable in terms of percentage contribution to the total cost. In similar vein, feed cost, water cost, labor cost, depreciation, medicaments and cost of salt lick are ranked 2nd, 3rd, 4th, 5th, 6th and 7th, respectively.

Table 2. Descriptive statistics of efficiency variables used for the study

Variable	Definition	Min	Max	Mean	Standard Dev.	Ranking of Inputs
Y	Revenue (₦)	90000	131000	119056	6864.09	-
X_1	Initial cost (₦)	55000	85000	68830	7457.60	(83.83%) 1st
X_2	Feed cost (₦)	10200	10660	10404	159.62	(10.86%) 2nd
X_3	Labor cost (₦)	4065	5210	4664	313.23	(4.87%) 4th
X_4	Medicaments (₦)	2400	5000	3496	605.98	(3.65%) 6th
X_5	Water cost (₦)	4000	5500	4712	360.50	(4.92%) 3rd
X_6	Depreciation (₦)	3300	4100	3682	238.63	(3.84%) 5th
X_7	Cost of salt lick (₦)	30	50	41.22	5.94	(0.04%) 7th

Source: Field Survey, 2018; 1₦=0.0028US$

Table 3 indicates the result of output oriented TE estimated based on the conventional DEA estimator across Variable Returns to Scale (VRS), Constant Returns to Scale (CRS), Non-Increasing Returns to Scale (NIRTS), Scale Efficiency (SE) and Returns to Scale (RTS). The mean TE_{VRS}=0.9244, indicates 92.44% efficiency level or 7.56% inefficiency level. This means that even at the current production technology and input level, there is room for increasing output by up to 7.56%. The TE_{VRS} ranges between 68.70% to 100% as minimum and maximum TE; indicates a slight variation in the efficiency scores among the cattle feedlot farmers in the area. In similar vein, the result shows 91.62% and 92.11% as estimates under TE_{CRS} and TE_{NIRTS}, respectively. In this study, the mean SE (0.9912) surpasses the TE_{VRS} (0.9244); suggesting inefficiency in the cattle feedlot is largely due to managerial issues. Padilla-Fernandez and Nuthall (2012) asserted that when SE is higher than the TE_{VRS}, it is an indication that a managerial problem is the major issue causing inefficiency rather than inappropriate size of production. Managerial problems in this context may take the form of over pricing of inputs, over utilisation/application of inputs and wrong timing for input utilisation/application (often resulting to input waste). Duckworth (2013) further asserted that the foregoing mostly occurs when the calves, feeds and other inputs are bought at record high prices. On the other hand, the TE_{SE} shows 50% of the farmers produce on the frontier; thus scale efficient, while the remaining 50% scale inefficient.

Table 3. Technical efficiency (TE) estimates disaggregated according to VRS, CRS and SE assumptions based on data envelopment analysis (DEA) estimator

TE Range	VRS (OTE)	CRS (PTE)	NIRTS	SE	RTS
Very low (0.0000-0.2500)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Low (0.2501-0.5000)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
High (0.5001-0.7500)	4 (1.48)	5 (1.85)	4 (1.48)	0 (0.00)	0 (0.00)
Very high (0.7501-0.9999)	228 (84.44)	238 (88.15)	237 (87.78)	135 (50.00)	92 (34.07)
Fully efficient (Exactly 1.0000)	38 (14.07)	27 (10.00)	29 (10.74)	135 (50.00)	178 (65.93)
Total	270 (100.00)	270 (100.00)	270 (100.00)	270 (100.00)	270 (100.00)
Summary					
Minimum	0.6870	0.6682	0.6870	0.8796	0.9597
Maximum	1.0000	1.0000	1.0000	1.0000	1.0000
Mean	0.9244	0.9162	0.9211	0.9912	0.9946
SD	0.0570	0.0579	0.0554	0.0144	0.0099

Source: Field Survey, 2018

In terms of TE_{RTS}, about 66% of the farmers produce at increasing returns to scale, while 34% operate at decreasing returns to scale. Bielik and Rajcaniova (2004) stated that continuous production for farms operating at increasing returns to scale leads to higher marginal returns and lower marginal costs, while for farms under decreasing returns to scale, continuous production results in lower marginal returns and higher marginal costs. It is therefore, imperative for 178 cattle feedlot farmers operating under increasing returns to scale to increase their size of operation to attract higher marginal returns and lower marginal costs. Similarly, it is rational for the 92 farmers operating under decreasing returns to scale down their operations. Based on the foregoing analogy, it suffices to deduce that both managerial and inappropriate scale of production explain the scenario of cattle feedlot in this study.

The result in Table 4 shows technical efficiency in the cattle feedlot system across FDH, Order-α and Order-m estimators; note the Order-m estimator was estimated under a default 2000 replications. In terms of minimum efficiency level, the FDH estimator (68.70%) was adjudged the lowest, next, the Order-m estimator (68.74%) and Order-α (80.00%); the highest. On average, the FDH estimator shows 93.01% mean efficiency level, the Order-m estimator produces at 93.21% mean efficiency, while the Order-α, at 96.50% mean efficiency. Similarly, the Order-α estimator produces the highest fully efficient DMUs or feedlot units; 111 feedlot units, representing 59% of the total feedlot units. The FDH and Order-m estimators each produce 52 feedlot units or 19% of total feedlot units apiece (Figure 2).

Table 4. Technical efficiency (TE) estimates based on free disposal hull (FDH), Order-α, Order-m estimators in cattle feedlot in Adamawa State, Nigeria

TE Range	TE $_{\text{FDH Estimator}}$	TE $_{\text{Order-α Estimator}}$	TE $_{\text{Order-m Estimator (NREP= 2000)}}$
Very low (0.0000-0.2500)	0 (0.00)	0 (0.00)	0 (0.00)
Low (0.2501-0.5000)	0 (0.00)	0 (0.00)	0 (0.00)
High (0.5001-0.7500)	4 (1.48)	0 (0.00)	4 (1.48)
Very high (0.7501-0.9999)	214 (79.26)	159 (41.11)	214 (79.26)
Fully efficient (Exactly 1.0000)	52 (19.26)	111 (58.89)	52 (19.26)
Total	270 (100.00)	270 (100.00)	270 (100.00)
Summary			
Minimum	0.6870	0.8000	0.6874
Maximum	1.0000	1.0000	1.0000
Mean	0.9301	0.9650	0.9321
SD	0.0579	0.0413	0.0574

Source: Field Survey, 2018; TE- technical efficiency

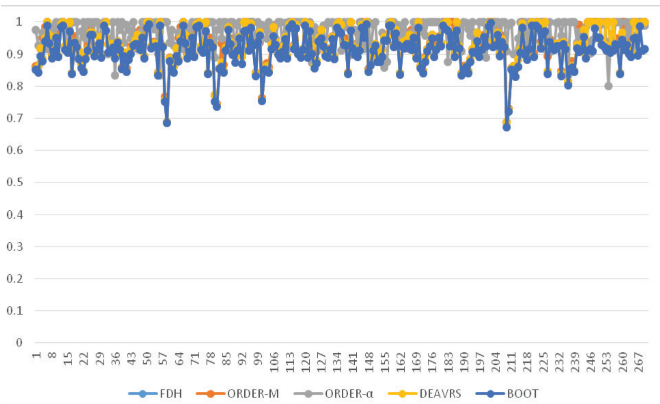

Figure 2. Comparative trend in technical efficiency of cattle feedlot estimated under FDH, Order-m, Order-α, DEA and Bootstrap estimators

The result of homogeneous smoothed bootstrap for technical efficiency in cattle feedlot system in Adamawa State is presented in Table 5. The result is based on simulation technique generated by 2000 replications. It shows non-biased corrected technical efficiency otherwise TE_{DEA}, the bias-corrected TE, the bias estimate, lower and upper limits for the bias estimate. The $TE_{bootstrap}$ shows none of the farmers operates either on the frontier or at low efficiency; only 1.48% of the farms operate at high efficiency level. About 99% of the farms produce at very high efficiency level. The mean $TE_{bootstrap}$ shows 67.18% and 99.75% as minimum and maximum efficiency, respectively; while 91.75% as mean efficiency. This means that output could increase by 8.25%, while maintaining the same input bundles. The cattle feedlot system is not free from bias, although minimal; with 1.29% as mean. The bias indicates the presence of noise.

Table 5. Technical efficiency (TE) based on bootstrap estimator in cattle feedlot system of Adamawa State, Nigeria

TE Range	$TE\text{-}_{DEA}$	$TE\text{-}_{Bootstrap}$ (BCTE)	Bias	Conf. interval for BCTE	
Very low (0.0000-0.2500)	0 (0.00)	0 (0.00)	-	-	-
Low (0.2501-0.5000)	0 (0.00)	0 (0.00)	-	-	-
High (0.5001-0.7500)	4 (1.48)	4 (1.48)	-	-	-
Very high (0.7501-0.9999)	228 (84.44)	266 (98.52)	-	-	-
Fully efficient (Exactly 1.0000)	38 (14.07)	0 (0.00)	-	-	-
Total	270 (100.00)	270 (100.00)	-	-	-
Summary					
Minimum	0.6870	0.6718	0.0008	0.6384 –	0.6868
Maximum	1.0000	0.9975	0.0909	0.9923 –	1.0000
Mean	0.9244	0.9115	0.0129	0.8878 –	0.9240
SD	0.0570	0.0528	0.0160	0.0527 –	0.0569

Source: Field Survey, 2018; DEA- Data Envelopment Analysis

Table 6 compares the mean technical efficiency estimates in the cattle feedlot system under the various estimators used. From the table, it can be seen that there is $P<0.01$ significant difference in TE scores in the cattle feedlot between FDH and Order-α, FDH and Bootstrap, Order-m and Order-α, Order-m and Bootstrap, Order-α and DEA, Order-α and Bootstrap and DEA and Bootstrap. This implies that the mean TE scores under the above combined estimators did not differ or are similar. Similarly, it can be depicted from the table that there is a non-significant difference in mean TE scores between FDH and Order-m, FDH and DEA and Order-m and DEA estimators. This further implies that there is significant variation or dissimilarity in TE scores under the foregoing combined estimators. By way of ranking, the Bootstrap and Order-α (4 appearances of significant difference) are ranked the most significant TE estimators in cattle feedlot system in Adamawa State. However, the FDH, DEA and Order-m (2 appearances each) are the next significant estimators in the cattle feedlot system.

Table 6. Probability (P-Value) matrix of hypothesis test for mean comparison in technical efficiency of cattle feedlot under FDH, Order-m, Order- α, DEA and Bootstrap Estimators

	FDH	ORDER-m	ORDER-α	DEA	BOOTSTRAP
FDH	NA	0.6940	0.0000***	0.2447	0.0001***
ORDER-m	-	NA	0.0000***	0.1177	0.0000***
ORDER-α	-	-	NA	0.0000***	0.0000***
DEA	-	-	-	NA	0.0066***
BOOTSTRAP	-	-	-	-	NA

Source: Field Survey, 2018; FDH- Free Disposal Hull; DEA- Data Envelopment Analysis

Conclusion

This study has shown initial cost of bull, feed, labour, depreciation, medicaments and salt lick as the 1st, 2nd, 3rd, 4th, 5th, 6th and 7th most important factors of production in the cattle feedlot system in Adamawa State, Nigeria. It has also shown the bootstrap and Order-α as the most significant technical efficiency (TE) estimators in the study area, while Free Disposal Hull (FDH), Data Envelopment Analysis (DEA) and Order-m as the next set of significant TE estimators in the area. Further, it has unraveled that the cattle feedlot system operates at very high TE but not on the frontier under all estimators. The study therefore, recommends proper pricing of inputs and timely utilization of inputs to avert input waste. Furthermore, it is imperative for 178 cattle feedlot farmers operating under IRS to increase their size of operation to attract higher marginal returns and lower marginal costs. Similarly, it is rational for the 92 farmers operating under DRS to downsize their operations.

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