Bootstrapped Data Envelopment Analysis (DEA) for Estimating Bias in Technical, Allocative and Economic Efficiency of Rainy and Dry Seasons Irish Potato Production in Plateau State, Nigeria

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Direct Research Journal of Public Health and Environmental Technology

Direct RESEARCH JOURNALS

Vol. 11(1), Pp. 114-119, April 2026

Research Article
ISSN: 2734-2182
https://journals.directresearchpublisher.org/index.php/drjphet; https://www.ajol.info/index.php/drjphet

Received 10 January 2026, Accepted 28 March 2026, Published 14 April 2026

ABSTRACT

This study used the bootstrapped DEA analysis for estimating bias in the technical, allocative and economic efficiency scores of rainy and dry season's Irish potato production among smallholder farmers in five selected Irish potato producing areas of Plateau state, North Central Nigeria. A random sample of 472 Irish Potato farmers was selected for the study. The primary data was analyzed using double bootstrap Data Envelopment Analysis (DEA). Results of rainy season Variable Return to Scale (VRS) DEA shows average technical efficiency (TE) for radial, non-radial and bias-corrected estimates to be 0.90, 0.70 and 0.68, respectively. The mean allocative and economic efficiency level was found to be 0.74 and 0.64 respectively. The dry season VRS DEA reveals average TE for radial, non-radial and bias-corrected estimates to be0.95, 0.79 and 0.84 respectively with a mean allocative and economic efficiency of 0.60 and 0.56. The estimated radial TE scores were higher than the bias-corrected TE scores indicating overestimation of the radial scores which in turn leads to bias results. In conclusion, the bias-corrected technical efficiency scores, the dry season Irish potato farmers were more efficient in their use of input resources than their rainy season counterpart. The study recommends that extension workers and policy makers should guide policies towards expanding efficiency in the study area.

Keywords: *Data Envelopment Analysis, Botstrap, Bias, Technical, Allocative, Economic, Efficiency*

Citation: Abubakar, M. I., Otse, F. A., Yakubu, A. A. & Alhassan, J. (2026). Bootstrapped Data Envelopment Analysis (DEA) for Estimating Bias in Technical, Allocative and Economic Efficiency of Rainy and Dry Seasons Irish Potato Production in Plateau State, Nigeria. *Direct Research Journal of Public Health and Environmental.* Vol. 11(1), Pp. 114-119.
https://doi.org/10.26765/DRJPHET50851250

INTRODUCTION

Data Envelopment Analysis (DEA) is among the most known and applied nonparametric techniques for the measurement of the efficiency in production and service activities. Nevertheless, this traditional non-parametric approach presents severe limitations that are not always taken into account by researchers who apply it in empirical works. One traditional limitation of the nonparametric approach is its deterministic nature (meaning that all deviations from the efficient frontier are considered as inefficiency; and no noise is allowed) and the difficulty in making statistical inference. In the nonparametric approach, statistical inference is not easy, due to the complex nature of the estimation which is based on very few assumptions. Nevertheless, advances have been made, and statistical inference is available by using the asymptotic results (Daraio and Simar, 2007; or by applying the bootstrap (Simar and Wilson,1998; 2000 Simar and Wilson, 2003).

Simar and Wilson (2000a) were the first to report on the limitations and advancements in nonparametric methods in frontier analysis.. The proposed advancements for overcoming the deterministic nature and no easy inference include bootstrapping,, hypothesis testing, noise and statistical properties. Following this proposed advancements, this present study used the bootsrapp for estimating bias. The bootstrap is a data - based simulation method for statistical inference. Statistical bootstrap is a method of estimation of the sampling distribution of an estimator or statistics by resampling from the original data. The idea of the bootstrap was first laid out with a well-developed theory in the seminal work of Efron (1979), although some related ideas were proposed before that and much of the theory was developed later (Chowdhury & Zelenyuk, 2016).

Bootstrapping is a method of testing the reliability of a data set by creating a pseudo-replicate data set. The simple idea of the bootstrap procedure is resampling the data with replacement and simulating a true sampling distribution by mimicking the data generating process. The reason for using the bootstrap procedure is to generate bias-corrected technical efficiency (BCTE) scores and obtain consistent statistical inference within models explaining efficiency scores (Badunenko & Mozharovskyi, 2016). Following Simar & Wilson (2007) modified by Badunenko & Tauchmann (2019), the double bootstrap procedure was used to estimate the technical efficiency scores from the input-oriented approach and identify the factors influencing the technical efficiency scores.

Chowdhury and Zelenyuk (2016) use bootstrap to estimate the bias of an estimator, first recall that the bias of an estimator $\theta^{\wedge}_{n}$ for the true θ is defined as:

$Bias_F\ (\theta^{\wedge}_{n})$ = E $(\theta^{\wedge}_{n}) - \theta$

$Bias_{F^{\wedge}_{n}}\ (\theta^{\wedge *}_{n,b}) = E_{F^{\wedge}_{n}}(\theta^{\wedge *}_{n,b})\ - \theta^{\wedge}_{n}$

The intuition of the method is again based on the fundamental expression: when it is true, i.e., $\theta^{\wedge *}_{n,b} - \theta^{\wedge}_{n} \mid F^{\wedge}_{n} \sim \theta^{\wedge}_{n} - \theta|\text{F}$,

then it would also ensure $(\theta^{\wedge *}_{n,b}) - \theta^{\wedge}_{n} \sim E_F\ (\theta^{\wedge}_{n}) - \theta - \theta$ and so $Bias_{F^{\wedge}_{n}}(\theta^{\wedge *}_{n,b}) \approx Bias_F\ (\theta^{\wedge}_{n})$. In turn, the unknown $E_{F^{\wedge}_{n}}(\theta^{\wedge *}_{n,b})$ can be approximated with any level of precision by its Monte Carlo analogue, via, and so, the bootstrap estimated bias of $\theta^{\wedge}_{n}$with respect to θ would be $\widehat{Bias}_{F^{\wedge}_{n}}(\theta^{\wedge}_{n}) = \frac{1}{B}\sum_{b=1}^{B}\theta^{\wedge *}_{n,b} - \theta^{\wedge}_{n}$

And, the resulting bias corrected estimate of θ would be

$\theta^{\wedge bcor}_{n} = \theta^{\wedge}_{n} - \widehat{Bias}_{F^{\wedge}_{n}}(\theta^{\wedge}_{n}) = 2\theta^{\wedge}_{n} - \frac{1}{B}\sum_{b=1}^{B}\theta^{\wedge *}_{n,b}$

Empirical Review

Hudu *et al.* (2018) in their study examined the profitability of Irish Potato farmers in Plateau State. A cross-sectional survey of 80 farmers selected through a multistage sampling effort was done and descriptive statistics and gross margin tool were employed in the data analysis. The study revealed that 62.50 percent of Irish Potato farmers were in the age bracket of 36-45 years and both male and female engaged in Irish Potato production in the area. Majority (53.8 percent) of the farmers were married with mean household size of 9 members. Majority (86.2 percent) of Irish Potato farmers in the area attended school. The production of the crop was found to be profitable with a mean income of ₦48,400 per ha and returns on investment (ROI) of ₦1.34. The constraints that limit productivity of the farmers were Potato blight disease, high input costs and poor infrastructures.

Obi-Egbedi & Gulak (2020), analyses the profitability of Irish Potato farming using primary data from 252 Irish Potato farmers in Plateau State, Nigeria. Cost structure and profitability level of Irish Potato farming were investigated using farm budgeting technique while probit regression model was used to examine the determinants of profitability level of Irish Potato farms. Irish Potato farming was found to be profitable with most (53.97 percent) farmers at high profitability level. The net farm income was ₦604,245.81 per hectare with returns per naira spent of ₦1.70. The cost structure showed that costs of seeds, labour and fertilizer made up the largest share of the total cost of production per hectare. It was concluded that increasing agrochemicals, reducing farm size and labour and being a male farmer will improve profitability level of Irish potato farms.

Uche *et al.* (2020) assessed the profitability of Irish Potato production in Plateau State, Nigeria. A multistage sampling technique was employed to select 180 respondents. Data were analyzed using descriptive statistics and gross margin analysis. The return on naira invested was estimated at ₦0.29 kobo. The mean output of potato in the area was 3,742.8kg per hectare. Labour utilization for potato production also revealed high variability. The mean labour utilized by respondents was 4.25 man-days per hectare while the maximum was as high as 545.33 man-days per hectare. About 65 percent of the total variable cost was expended on seed at the cost of ₦215,263.3/ha. The gross margin of the Potato enterprise was ₦95, 986.86 /ha. The RNI was ₦1.29. The study further shows that high costs of inputs, inadequate credit facilities, pests and diseases, lack of security were major constraints to Irish Potato production in the study area. Mwatawala *et al.* (2020) investigated strategies for enhancing productivity and profitability of Irish potato in the Mbeya District, Tanzania. Data from a sample of 192 smallholder farmers were analyzed by employing descriptive and inferential statistics. The average yield was 6,853 kg of Irish potato per acre. The gross return per acre was Tanzania shilling (TZS) 4,690,022, while the total variable cost was TZS 1,926,402 making the gross margin of TZS 2,763,620 per acre. Although this profit margin seems low it is, in fact, higher than expected mainly because data was collected during low season when farm gate prices were relatively high. Education level of a farmer, access to credit, membership in farmers' groups, farm size, and household size significantly influenced Irish potato profitability among smallholder farmers. The strategies for enhancing productivity included distribution of improved potato varieties, training smallholders on good agronomic practices (GAP), and sensitizing smallholders to form or join farmer groups or associations for collective marketing.

METHODOLOGY

This study was conducted in Plateau State, which is located in the North Central Nigeria. The State lies between Latitude 8^0 North and 10^0 North and Longitude 7^0 East and 11^0East of the prime meridian (Uche *et al.,* 2020). Multi-stage sampling procedure was adopted for this study to select Irish potato farmers from the five (5) major Irish potato producing Local Government Areas (LGAs) in Plateau State, Nigeria. The sample size of 362 farmers was randomly selected from a sample frame of 3,911 Irish potato farmers.

Model Specification

DEA is a mathematical model using linear programming approaches to create a nonparametric piecewise surface (or frontier) across the data, so that efficiencies can be calculated in relation to this surface. DEA was suggested in late sentries by Charnes *et al* (1978); they set up a model of constant returns to scale (CRS) named the CCR. The model was later adjusted by Banker *et al* (1996) to enable the presence of variant returns to scale (VRS) and became identified as BCC. DEA's efficiency is explained in three main structures, namely, technical efficiency, allocative efficiency and economic efficiency. The efficiency scores of all these forms are always less than or equal to one (Hassan, 2021).

RESULTS AND DISCUSSION

Estimation of rainy season farm level technical efficiency scores

Results of rainy season Variable Return to Scale (VRS) DEA shows average technical efficiency (TE) for radial, non-radial and bias-corrected estimates to be 0.90, 0.70 and 0.68, (Table 1). The mean allocative and economic efficiency level was found to be 0.74 and 0.64 respectively.

Estimation of allocative and economic efficiency scores for rainy season Irish potato farmers

Table 2 shows the summary statistics and frequency distribution of the allocative efficiency (AE) and economic efficiency (EE) of rainy season Irish Potato farmers obtained from VRS-DEA model. The results showed that 26.95 percent of the Irish Potato farmers had an efficiency score of 0.7 – 0.79 for allocative efficiency while for the economic efficiency 25.00 percent of the Irish Potato farmers had an efficiency score of 0.5 – 0.59. Also, only 13.64 percent and 7.79 percent rainy season Irish Potato farmers had an efficiency score ≥0.9 for allocative efficiency and economic efficiency respectively. This implies that very few Irish potato farmers in the rainy season production were able to utilised available inputs in ideal amounts given their individual prices, and given the current state of technology. This finding contradict the report by Hassan, (2021), that majority of efficient broiler farmers in Iran were operating at allocative and economic efficiency range between 0.90 – 0.99, and that the large grade of allocative and economic efficiency proposes so little outputs are being lost to waste resources.

From the VRS DEA results obtained, the average allocative efficiency of the rainy season Irish Potato farmers was 0.74, with minimum and maximum efficiency scores of 0.33 and 1 respectively, meaning that if these farmers operated at full allocative efficiency, they could lower their production costs by 0.26 percent while producing the same amount of output. The average economic efficiency level is 0.64, with minimum and maximum efficiency scores of 0.22 and 1 respectively. That means a farmer with an average level of economic efficiency may cut the current average production costs by 36 percent to reach the minimum cost level while maintaining the same output level. This also indicates that, a rainy season Irish potato farmer with a mean level of economic efficiency would save production cost by 36 percent [(1-(0.64/1)] x 100} to reach the level of most economically efficient producer. This study is in consonance with the findings of Gautam *et al.*(2020) andHassan, (2021) butreveals a lower efficiency scores compared to the efficiency scores reported by Hassan, (2021). According to Hassan, (2021), efficiency is a relative concept affected by differences in methodology choice, variables specification, and production cost.

Table 1: Distribution of Rainy Season Farmers by Technical Efficiency Scores.

DEA VRS assumption technical efficiency						
	Radial TE		Non-radial(Slack-based) TE		Bias-corrected TE	
Efficiency Range	**Freq.**	**Percent**	**Freq.**	**Percent**	**Freq.**	**Percent**
< 60	8	6.6	36	29.8	39	32.8
60 – 79	24	19.8	55	45.4	45	37.8
≥80	89	73.6	30	24.8	35	29.4
Total	121	100	121	100	119	100
Efficiency scores						
Mean	0.90		0.70		0.68	
Minimum	0.47		0.37		0.26	
Maximum	1		1		1	
Std. Dev.	0.15		0.17		0.16	

Source: Field survey, 2024/2025. Std. Dev. = Standard Deviation

Table 2: Distribution of Allocative and Economic efficiency Scores for Rainy Season Irish Potato Farmers.

DEA VRS assumption efficiencies estimate				
	Allocative Efficiency AE		Economic Efficiency EE	
Efficiency Range	**Freq**	**Percent**	**Freq**	**Percent**
≤ 0.49	21	7.14	62	20.13
0.5 – 0.59	34	11.04	77	25.00
0.6 – 0.69	57	18.51	57	18.51
0.7 – 0.79	83	26.95	56	18.18
0.8 – 0.89	70	22.73	32	10.39
≥ 0.9	42	13.64	24	7.79
Total	308	100	308	100
Efficiency scores				
Mean	0.74		0.64	
Minimum	0.33		0.22	
Maximum	1		1	
Std. Dev.	0.14		0.16	

Source: Field survey, 2024/2025. Std. Dev. = Standard Deviation

Table 3: Distribution of Dry Season Farmers by Technical Efficiency Scores.

DEA VRS assumption technical efficiency estimates						
	Radial TE		Non-radial(Slack-based) TE		Bias-corrected TE	
Efficiency Range	**Freq.**	**Percent**	**Freq.**	**Percent**	**Freq.**	**Percent**
< 60	1	1.1	11	11.8	6	6.5
60 – 79	12	12.9	43	46.2	24	25.8
≥80	80	86.0	39	42.0	63	67.7
Total	93	100	93	100	93	100
Efficiency scores						
Mean	0.95		0.79		0.84	
Minimum	0.52		0.46		0.28	
Maximum	1		1		1	
Std. Dev.	0.11		0.15		0.19	

Source: Field survey, 2024/2025. Std. Dev. = Standard deviation

Estimation of dry season farm level technical efficiency scores

The dry season VRS DEA reveals average TE for radial, non-radial and bias-corrected estimates to be0.95, 0.79 and 0.84 respectively with a mean allocative and economic efficiency of 0.60 and 0.56. The estimated radial TE scores were higher than the bias-corrected TE scores indicating overestimation of the radial scores which in turn leads to bias results (Table 3).

Estimation of allocative and economic efficiency scores for dry season Irish potato

The frequency distribution of the allocative efficiency and economic efficiency estimates of dry season Irish potato farmers is presented in (Table 4) as obtained from the VRS DEA analysis. It was observed from the study that the allocative efficiency score between0.5 – 0.69 had 40.86 percent, while 38.71 percent operates between0.3 – 0.49 economic efficiency.

Table 4: Distribution of Allocative and Economic Efficiency Scores for Dry Season Irish Potato Farmers.

	DEA VRS assumption efficiencies estimate			
	Allocative Efficiency AE		Economic Efficiency EE	
Efficiency Range	**Freq**	**Percent**	**Freq**	**Percent**
< 0.3	5	5.38	5	5.38
0.3 – 0.49	24	25.81	36	38.71
0.5 – 0.69	38	40.86	32	34.41
0.7 – 0.89	18	19.35	13	13.98
≥ 0.9	8	8.60	7	7.53
Total	93	100	93	100
Efficiency scores				
Mean	0.60		0.56	
Minimum	0.20		0.20	
Maximum	1		1	
Std. Dev.	0.18		0.19	

Source: Field survey, 2024/2025. Std. Dev. = Standard deviation

Table 5: Distribution of Technical Efficiency Scores for Pooled Sample

	DEA VRS assumption technical efficiency					
Efficiency Range	**Radial TE**		**Non-radial(Slack-based) TE**		**Bias-corrected TE**	
	Freq.	**Percent**	**Freq.**	**Percent**	**Freq.**	**Percent**
< 60	17	7.94	89	41.59	55	25.94
60 – 69	19	8.88	41	19.16	33	15.57
70 – 79	15	7.01	40	18.69	34	16.04
80 – 89	9	4.21	20	9.35	36	16.98
≥ 90	154	71.96	24	11.21	54	25.47
Total	214	100	214	100	212	100
Efficiency scores						
Mean	0.90		0.66		0.74	
Minimum	0.38		0.31		0.30	
Maximum	1		1		1	
Std. Dev.	0.16		0.17		0.17	

Source: Field survey, 2024/2025. Std. Dev. = Standard deviation

These show the highest concentration or percentage of farmers who were unable to allocate cost efficiently as well as those farmers that were not economically efficient. From the results also, only 8.60 percent obtained allocative efficiency score ≥0.9, while for economic efficiency only 7.53 percent were able to achieved economic efficiency score ≥0.9. This implies that very few of the dry season Irish potato are really allocatively and economically efficient. This result is in consonance with the findings of (Hudu *et al*., 2023).

Estimation of pooled sampled farm level technical efficiency scores

The efficiency scores of the pooled sampled from the VRS DEA models are presented in (Table 5). Technical efficiency for radial measure ranges from 0.38 to 1 with a mean of 0.90in the second column. Thus, the most technically efficient Irish potato farmer is operating on the frontier in this model. Therefore, if the average Irish potato farmer in the sample was to achieve the technical efficiency level of its most efficient counterpart, then the average Irish potato farmer could reduce 10 percent [i.e (1–0.90) x100] of input use without changing output level. That is on average, the sampled farmers can increase current output level by 10 percent without increasing existing levels of inputs. A similar calculation for the most technically inefficiency Irish potato farm household reveals input saving of 0.62 percent [i.e., (1– 0.38) x 100]. This result is in congruence with Chung *et al*. (2020) and Long *et al*. (2020a).

Estimation of Pooled allocative and economic efficiency scores for Irish potato farmers

The result presented in (Table 6) shows the allocative efficiency (AE) and economic efficiency (EE) of Irish potato farmers obtained from the VRS DEA analysis. The results from VRS-DEA model showed that 37.66 percent of the farmers had an efficiency score of 0.60 – 0.79 for allocative efficiency while for the economic efficiency 38.15 percent of the Irish potato farmers had an efficiency score of 0.4 – 0.59. Also, 28.68 percent and 14.21 percent Irish potato farmers had an efficiency score ≥80 for allocative efficiency and economic efficiency respectively. Suggesting that the Irish potato farmers were able to obtain AE and EE of 80 percent and above through the utilization of inputs in required amount given their individual prices and given the current state of technology. The result is in line with (Shiferaw *et al.*, 2022).

Table 6: Distribution of Allocative and Economic Efficiency Scores for Pooled Sample.

DEA VRS assumption efficiencies estimate				
Allocative Efficiency AE	**Economic Efficiency EE**			
Efiiciency Range	**Freq**	**Percent**	**Freq**	**Percent**
<0.40	54	13.47	72	17.96
0.40 – 0.59	18	20.20	153	38.15
0.60 – 0.79	151	37.66	119	29.68
≥ 0.80	115	28.68	57	14.21
Total	401	100	401	100
Efficiency scores				
Mean	0.66		0.58	
Minimum	0.09		0.09	
Maximum	1		1	
Std. Dev.	0.21		0.20	

Source: Field survey, 2024/2025. Std. dev. = Standard deviation

Conclusion and Recommendations

Based on the findings of this study, it could be concluded that the bootstrap procedure minimized the sample sensitivity due to biased and serially correlated estimates. After correcting for bias, the average technical efficiency score tends to be lower for bias-corrected (bootstrapped) DEA measures than the conventional radial DEA measures. Based on the bias-corrected technical efficiency scores, dry season Irish potato farmers were more efficient in their use of input resources than their rainy season counterpart. The study recommends that extension workers and policy makers should guide policies towards expanding efficiency in the study area

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