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Measuring the Technical Efficiency of Cotton Farmers Using Stochastic Frontier and Data Envelopment Analysis: A Case Study of Northeast Zone, Nigeria

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Abstract: *The measuring of technical efficiency for cotton farms can be invaluable in estimating optimum farming practices and in identifying premeditated options for the farmers. Therefore, this paper investigates the technical efficiency of sampled cotton farmers in Northeast zone of Nigeria, using a Stochastic frontier production function (SFA), constant returns to scale (CRS) and variable returns to scale (VRS) of output-oriented Data Envelopment Analysis (DEA). Data were obtained from 349 cotton farmers using a structured questionnaire interviews. The estimates of technical efficiency based on these two aforementioned frontier methods were compared. While efficiency scores for cotton farmers differed between the SFA and the DEA models, the mean efficiency scores are fairly low for the CRS DEA model compared with the VRS DEA and SFA approaches. The mean efficiency measure (0.91) obtained from the stochastic frontier was also lower than the calculated VRS DEA (0.93) but higher than the CRS DEA (0.88). This study suggests that the role of adopting high yield variety of improved cotton seeds not only reduces inefficiency but also increases the mutual effect of inputs on the output variance, whereas technical efficiency enhances the variability of cotton production in the study area.*

Contribution/ Originality:*The determination of technical efficiency for cotton farms can be invaluable in estimating optimum farming practices and in identifying strategic options for the farmers. Therefore, this paper is to measure the technical efficiency of cotton farmers using stochastic frontier(SFA) and data envelopment analysis (DEA), using Northeast zone in Nigeria as a case study.*

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I. Introduction

Cotton is the significance product andconsidered one of the most important agricultural products in Nigeria and globally at large for it plays an important part in the economic development of any nation, as it contributes to its Gross Domestic Product (GDP) as well as creates jobs and income for farmers in that country. Cotton is used to make many textile products in the textile industry and used in fishing nets as well as paper and bookbinding. The cottonseed that remains after cotton is ginned to produce cottonseed oil, which, after refining, can be consumed by humans like any other vegetable oil. In addition, the cottonseed meal that is left is generally feed to ruminant livestock; while the gossypol remaining in the meal is toxic to monogastric animals. Cottonseed hulls can be added to dairy cattle rations for roughage (Anonymous, 2012) [1].

In Nigeria, however, there has been a severe decrease in cotton farming, as statistics revealed that the cotton contribution to the country's GDP fell woefully from 25 percent in 1980 to 5 percent as shown by the recent economic indicators. Though in terms of the nominal non-oil contribution to the domestic growth, the agricultural sectorhas contributed by 5.06 percent which was higher than 4.76 percent recorded in the preceding quarter, which the crop production contributed in the country of 4.23 percent, cotton has to be given prior attention by the government as a result of the set-back experienced in its production in the country (Kriger, 2005) [2].

As one of the majors taking by the government a council called Raw Materials Research and Development Councils (RMDRC) was set whose mandatory are to promote the development and optimal utilization of locally available raw materials by the manufacturing sector of the economy. In addition, the council is also to ensure the development of process equipment or adaptation of existing ones for use by the raw material sector. This is because the sector was one of the major industrial parts which the country had serious prideas its influence pervaded the whole of Africa and beyond, both in terms of employment generation and contribution to national GDP (National Bureau of Statistics, 2015) [3].

Table 1 shows that from 2012 to 2018, the country experienced down fall in the area under cultivation. This has negative effect on the yield as well as the volume in production. Though the country experienced 10 percent increase in the area cultivated in 2018, that does not make any impact in yield considering the production output, if we compare to that of 2015. In general, from 1979 to 2018 the situation of area under cultivation, the yield and cotton productivity has been in flux in the country. Notwithstanding, there is fluctuation as earlier stated and discussed, some time with an increase in productivity as in 1997, 2000 and 2018. The increase in these years' productivity leads to higher yields of cotton, as their production has shown an increasing trend over time. This may be attributed to the action taken by the Nigerian government, thereby leading to an increase in cotton yield if compared with the area planted in the trend. Therefore, it is clear that if the technical efficiencies of cotton farms could be evaluated in an informative way, options for improving the sustainability and profitability of cotton farming would be achieved in the study area.

Table1: Area Planted, Yield and Total Production in Nigeria 1979-2018

Year	Area(ha)	Yield (Kg/ha)	Production (Kg)
1979	240	124	29,780
1982	205	96	19,575
1985	220	46	10,005
1988	370	114	41,978
1991	430	140	60,030
1994	210	310	60,683
1997	350	200	70,035
2000	350	249	87,000
2003	380	241	90,263
2006	380	229	87,000
2009	395	248	97,875
2012	300	236	70,688
2015	260	193	50,025
2018	270	190	51,113

Source: USDA, (2018)[4]

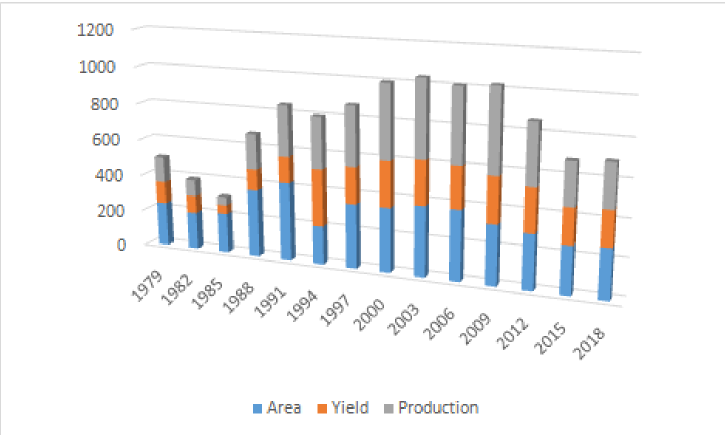

Figure 1: Planted area, average yield and total production in Nigeria.

II. Stochastic Frontier Analysis

Stochastic Frontier Analysis (SFA) is a parametric approach that hypothesizes a functional form and use the data to econometrically estimate the parameters of the function using the entire set of DMUs. The hypothesized function is used to calculate estimates of the efficiencies of individual DMUs. One of the SFA advantage is that it can separate random noise from efficiency and reveal overall sample-based information.

2.1 STOCHASTIC FRONTIER APPROACH

Here, we are going to explain the approach of parametric frontier called Stochastic Frontier Approach (SFA). It is the alternative method for estimating technical efficiency scores that was originally developed and independently proposed by two different authors: Meeusen & Van den Broeck (1977)[5] as published in International Economic Review in June whileAigner, Lovel, & Schmidt et al. (1977)[6] published in July in Journal of Economics. To adopt SFA technique, the production firm is assumed to be fully efficient and the

functional form must be appropriate and fit to the desired data. Although Stochastic Frontier Analysis can also function as Ordinary Least Square (OLS) in research study that involves production investigation, there are still existing differences between them. In Stochastic Frontier Analysis, maximum likelihood estimation is used while simple regression estimation is used in stochastic frontier analysis square. Coelli et al.(2005)[7] , pointed out that there are many desirable large sample properties (i.e. asymptotic) in maximum likelihood estimators. But simple regression analysis is employed to discover mean of production function.
The general SFA for cross-sectional data is specified as follows (Sharma *et al*, (1997 [8]; Wadud and White, (2000) [9]:

$$\boldsymbol{y_i = h(x_i;\alpha)\exp(\varepsilon_i)} \qquad \textbf{(1)}$$

Where i= 1,2,3…. N, y_i is the output realized by firm I and is bounded above by the stochastic component $h(x_i;\alpha)\exp(v_i)$. The $h(x_i;\alpha)$ is the production frontier, the x_i's represent the vector of inputs, α is a vector of the unknown technology parameters. The composed error term is $\varepsilon_i = v_i - u_i$, where v_i captures the effect of the pure noise in the data that are attributed to measurement error, extreme weather conditions, etc. and the one-sided inefficiency effects are denoted as u_i. The variance parameters of the model are parameterized as:

$$\sigma_u^2 = \sigma_\xi^2 + \sigma_\zeta^2 \qquad \gamma = \frac{\sigma_\xi^2}{\sigma_u^2} \qquad 0 \le \gamma \le 1 \qquad \textbf{(2)}$$

The technical efficiency of an individual firm from the stochastic frontier perspective is termed as the ration of the output observed to the corresponding input used by the firm given the levels of inputs of the stochastic frontier. In this way, the firm's technical efficiency in the context of the stochastic frontier production function is given by:

$$\boldsymbol{TE_i = \frac{y_i}{y_i^*} = \frac{h(x_i;\alpha)\exp(u_i)}{h(x_i;\alpha)} = \exp(-u_i)} \qquad \textbf{(3)}$$

In the deterministic approach, all the deviations in output are viewed as technological inefficiency effects, that is, $\varepsilon_i = u_i$ regardless of the fact that the deviations in output might be contributed by random errors including weather effects and the measurement errors which are over and above the control of the farmers. Therefore, the basic stochastic model separates the pure noise component from the technical inefficiency effects.

III. Empirical Stochastic Frontier Model

The empirical version of the model presumes a trans log production frontier:

$$\ln Y_i = \beta_0 + \sum_{i=1}^{8}\sum_{j=1}^{8} \beta_{ij} \ln x_i \ln x_j + v_i - u_i \qquad \textbf{(4)}$$

where Y_i indicates the average unmined cotton production, x_1 represents the total seed costs during the production period, while x_2, x_3, x_4 and x_5 represent the costs of fertilizer and chemicals, per hectare respectively during the growing season. Eventually, *ln* denotes natural logarithms.

IV. Data Envelopment Analysis

Ordinarily, non-parametric approaches are mostly Data Envelopment Analysis (DEA) which does not need arbitrary assumptions of the functional forms or error term distribution. Gorton and Davidova (2004)[10], are of the opinion that the purpose behind the popularity of this applications is its computational ease and the possibility of isolating scale-efficiency from technical and allocative efficiency. Also, the non-parametric approaches use mathematical programming in constructing a production frontier that comprises a set of linear sectors. The non-parametric approaches envelopes the entire segments with the best input-output ratios. A linear programming (LP) technique within the context of DEA envelops the data and describes the best-practice reference technology by employing an output distance function. The measuring of technical efficiency within the scope of the output-oriented DEA investigates a proportionate increase in its output level, given its input utilization while remaining on the same production frontier (Wadud and White, (2000) [9].

The output-oriented DEA model for a single output is presented below (Sharma *et al*, 1997) [8]. Under the assumption of *n* decision-making units (DMU), each of them would produce a single output by employing *d*ifferent inputs. The i^{th} DMU employs *xKi* units of the *k*th input in the production of *yi*units of output. A separate problem is solved for each DMU. The variable returns to scale (VRS) output-oriented DEA model for the i^{th}DMU is determined by:

Max ϕ_i

$$\phi_i, \tau_i \qquad \textbf{(4a)}$$

Subject to:

$$\sum_{j=1}^{n} \tau_j y_j - s = 0$$

$$\sum \tau_j x_{kj} + e_k = x_{ki} \qquad \text{k=1,……..m inputs} \qquad \textbf{(4b)}$$

$$\sum \tau_j = 1 \qquad \text{j=1,…..n DMU} \qquad \textbf{(4c)}$$

$$\tau_J \geq 0;\ s \geq 0;\ e_S \geq 0; \qquad \textbf{(4d)}$$

where ϕ_i is the proportional increase in the output possible for the i^{th} DMU; *s* is the output slack; e_K is the *k*th input slack; and *i*is the weight of the j^{th} DMU. The constant returns to scale (CRS) output-oriented model is obtained by eliminating the constraint $\sum_{i=1}^{n} \tau_i = 1.$ The single output-oriented DEA model seeks to maximize the proportional increase in output while remaining within the production possibility set. The possible proportional increase in output is accomplished when the output slack, *s*, becomes zero. When the value of ϕ in Equation (5) is 1, $\tau_i = 1$ and $\tau_j = 0$ for $j \neq i,$ the i^{th}DMU lies on the frontier and is efficient. For the inefficient units, $\phi \succ 0.\ \tau_i = 0$ for $j \neq i.$The projected or frontier production level for the i^{th} DMU, represented by is presented by:

$$\hat{y} = \sum \tau_i y_j = \phi_i y_i \qquad \textbf{(5)}$$

The output-oriented measure of technical efficiency of the i^{th} DMU, represented by TE*i*, can be calculated by:

$$TE_i = \frac{y_i}{\hat{y}_i} = \frac{1}{\phi_i} \qquad \textbf{(6)}$$

which is consistent with the measure of technical efficiency achieved within the frame of the stochastic production frontier (Equation 2). The VRS frontier is more flexible and envelops the data in a tighter way than the CRS frontier. The technical efficiency score of the i^{th} DMU in the CRS circumstance TE_{iCRS} will be less than or equal to that in the VRS circumstance TE_{iVRS}. This connection is often employed to determine a measure of scale efficiency of the i^{th} DMU, SE*i*(Sharma *et al*, 1997) [8], as:

$$SE_i = \frac{TE_{iCRS}}{TE_{iVRS}} \qquad \textbf{(8)}$$

where SE*i* = 1 denotes scale efficiency and SE*i* < 1 represents scale inefficiency. Scale inefficiency is attributable to either increasing or decreasing returns to scale, which can be defined by inspecting the sum of weights under the estimation of CRS(Banker, 1984)[11]. If this sum is equal to one, we have constant returns to scale (optimal scale); if it is less than one, we have increasing returns to scale (suboptimal scale); and if it is higher than one, we have decreasing returns to scale (super optimal scale)(Sharma *et al*, 1997; [8] Wadud and White, 2000)[9].

V. Data Collection

5.1 Study area

The target population for the study are the cotton farmers in the three states of the Northeast zone: Adamawa, Gombe and Taraba State. Adamawa state has twenty-two (22) local governments and five (5) were selected. Gombe State has eleven (11) local governments and three (3) were selected. On the other hand, Taraba State has sixteen (16) local governments and four (4) were selected (Table 2).

Table 2: Selected Local Government from the study area

State	Local Government	Local Government Selected
Adamawa	22	5
Gombe	11	3
Taraba	16	4
Total	**49**	**12**

Source: Field Survey data, 2016

Also, the list of the cotton farmers was obtained fromAfcott out-growers scheme. In arriving at the representative sample for the study from the list therefore, a two-stage and simple random sampling (SRS) procedure for the choice of local government and cotton farmers was employed. A total of twelve (12) local government were selected as the first stage for the study through randomized sampling design out of forty-nine (49) local government in the study area. At the final (second) stage a total of 165 cotton farmers were selected out of 501 farmers in Adamawa state. In Gombe State 102 cotton farmers were selected out of 520, while 93 cotton farmers were selected from Taraba State out of 338 cotton farmers in the area. This gives the total of 360 sampled respondents out of 1359 cotton producers in the study area (Table 3).

Table 3: Sample Design Outlay for the Study

State	Selected Local Govt	Cotton Growers	Farmers
Adamawa	5	501	165
Gombe	3	520	102
Taraba	4	338	93
Total	**12**	**1359**	**360**

Source: Field Survey data, 2016

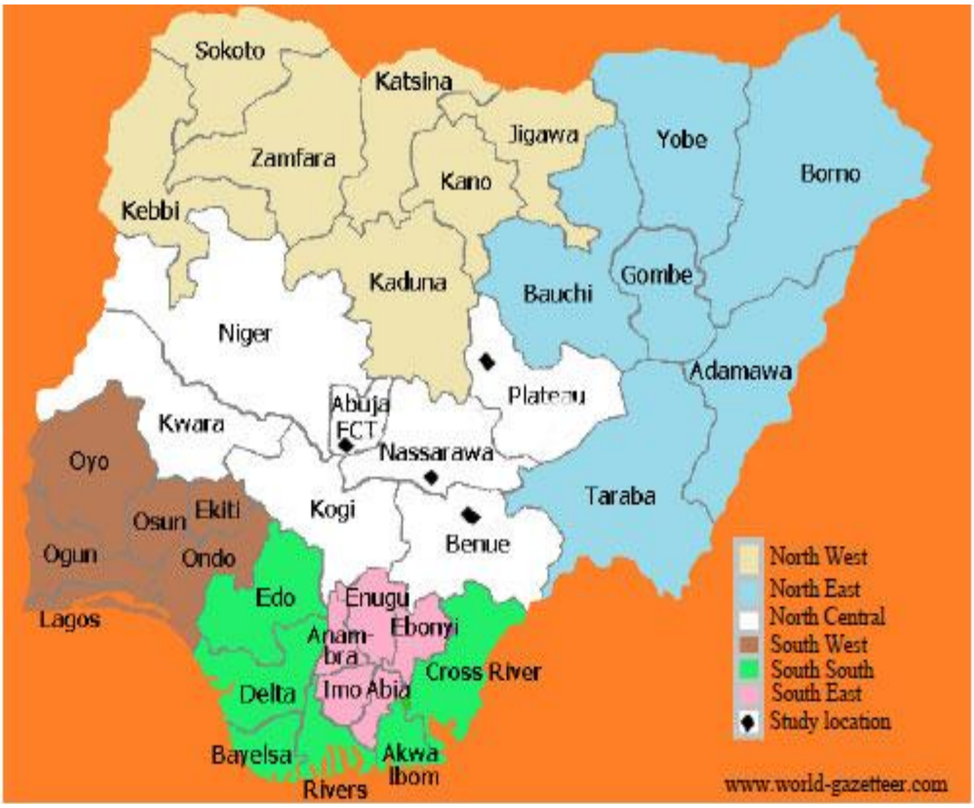

Figure2: Map of Nigeria, showing the study area in the Northeast
Source:(Abiayi et al., 2015) [10]

5.2 QUESTIONNAIRE DESIGN

The data were collected from the cross-section of cotton farmers for the 2016 cropping season in the study area through a structured questionnaire. These were administered by some trained enumerators in the study area by the researcher to make them understand the contents of the questionnaire, and on how to administer questions to the respondents in the study area in order to abide by research ethics. Consequently, the information on output and inputs-use to grow cotton by the respondents were collected for analysis.

VI. Results

6.1 STOCHASTIC FRONTIER ANALYSIS

The coefficients of the production function in SFA were estimated by employing Frontier Program Version 4.1(Coelli, 1996a)[13]. The Cobb-Douglas stochastic production function model was an insufficient representation of the data for the cotton farms investigated so far and the results obtained from the likelihood ratio test of p-values. The maximum likelihood estimates of the translog stochastic frontier model are represented in Table 4. The coefficients of the independent variables are significant at the 1%, 5% and 10% level of significant, suggesting that the model is a good fit. The variance parameter of the model (γ) was significantly different from zero indicating that 92% of the variation in output was as a result of technical inefficiency. The estimate value of sigma square (σ^2) with negative coefficient (-12.3) is indicating that a conventional cotton production function is not a sufficient representation of the data. The elasticities of output for seeds, fertilizer, chemicals and labour returns to scale elasticity of the translog stochastic frontier model are given in Table 5. The traditional elasticity of the output with respect to the k^{th} input indicated the formula fromBattese and Broca (1997) [14] as follows:

$$\eta_k = \beta_k + 2\beta_k x_{ki} + \sum_{j=k} \beta_{kj} x_{ji} \qquad \textbf{(9)}$$

In addition, from Table 5, we can see that the elasticity of output for seeds is highest among the elasticities of the inputs that are positive. The positive sign signifies that increase in these variables will increase output while the negative sign means that increase in the variable will decrease the level of output. Sequentially, the output elasticity for seed, fertilizer, agrochemicals and labour are 0.412 percent, 0.243 percent, 0.134 percent and -0.256 respectively. Furthermore, the elasticity result indicated that seed has the highest contribution to cotton production, followed by fertilizer and agrochemicals. On the other hand, labour has higher percentage too but with negative sign, indicating that the farmers in the study area should be watchful in using high labour as it may lead to a decrease of cotton output.

The return to scale elasticity of 0.533 indicates a strongly decreasing return to scale, technically efficient for the CRS. The scale efficiency index for the cotton farms is estimated by employing the equation $\tau_i^{SE} = \frac{\tau_i^{CRV}}{\tau_i^{VRS}}$, as the efficiency scores estimated under the VRS DEA frontier are equal to or greater than those determined under the CRS DEA. The scale efficiency index for the sample farmers ranges from 0.010 to 1.000, with a sample mean and standard deviation of 0.270.

Table 4: Maximum Likelihood Estimates for Parameters using translog

Variable	Parameter	Coefficient	Std Error	P-Value
Constant	γ_0	-2.0862*	0.6873	0.002
lnseed	γ_1	0.2789***	0.0438	0.000
lnfert	γ_2	0.2753***	0.0277	0.000
lnchem	γ_3	0.2046**	0.1212	0.092
lnlabour	γ_4	-0.2558	0.2565	0.319
lnseedsq	γ_5	0.4508***	0.1004	0.000
lnfertsq	γ_6	-0.0069	0.0410	0.865
lnchemssq	γ_7	-0.0158	0.0196	0.148
lnlaboursq	γ_8	0.0430	0.0274	0.117
(lnseed)(lnfert)	$\gamma_1 \gamma_2$	-0.2626*	0.1022	0.010

(lnseed)(lnchem)	$\gamma_1 \gamma_3$	-0.0154	0.0396	0.696
(lnseed)(lnlabour)	$\gamma_1 \gamma_4$	0.0398	0.0631	0.528
(lnfert)(lnchem)	$\gamma_2 \gamma_3$	0.0481	0.0392	0.220
(lnfert)(lnlabour)	$\gamma_2 \gamma_4$	-0.0735	0.0562	0.191
(lnchem)(lnlabour)	$\gamma_3 \gamma_4$	-0.0554*	0.0218	0.011
Variance Parameters				
Sigma-Square (u)		0.0842		
Sigma-Square (v)		0.0241		
Lambda ($\boldsymbol{\lambda = \delta_u/\delta_v}$)		3.4937		
Sigma^2($\boldsymbol{\delta^2 = \delta v^2 + \delta u^2}$)		-12.3979		
$\boldsymbol{Gamma}$ ($\boldsymbol{\gamma = \lambda^2/(+\lambda^2)}$)		0.924		

Source: Field Survey data 2016. **Note***, ** and*** denote significance at 5%, 10% and 1% level respectively.

Table 5: Elasticity for outputs in the Stochastic Frontier Production

Variable	**Elasticity**
Seed	0.412
Fertilizer	0.243
Chemical	0.134
Labour	-0.256
Return to Scale (RTS)	**0.533**

Source: Field Survey data, 2016.

VII. Comparison Between SFAandDEA Measure Results

Table 6 shows that the mean efficiency measure (0.913) obtained from the stochastic frontier is higher than that calculated from the VRS DEA (0.88) and that estimated from the CRS DEA (0.27). Although most cotton farmers could focus on the group that shows more efficient operating characteristics in the stochastic frontier and the VRS DEA, there are relatively few farmers in the efficient group in the CRS DEA. The efficiency results indicate that there is9–87% (Table 6) scope to increase cotton production with the existing technology and without additional inputs. It also paramount that the DEA measures have greater variability than the stochastic efficiency measures.

Table 6: Efficiency Estimates from both Stochastic Frontier and DEA models

Efficiency Score	SFA	CRS	VRS	SE
Mean	0.913	0.2753	0.8813	0.3235
Minimum	0.676	0.5930	0.5678	0.0100
Maximum	0.981	1.0000	1.0000	1.0000
Standard Deviation	0.062	0.2547	0.0789	0.3700
Skewness	-2.536	1.3845	0.5460	0.8974
Kurtosis	2,567	1.4500	0.7768	-0.04120

Source: Field Survey data, 2016.

Table 7: Efficiency Estimate of SFA and DEA models

	Stochastic Frontier	DEA Model		
Efficiency Score	TE_{SFA}	TE_{CRS}	TE_{VRS}	SE
1.00	0	0	30	54
> 0.90 < 1	250	45	230	37
> 0.80 ≤ 0.90	71	67	81	87
> 0.70 ≤ 0.80	23	12	8	88
> 0.60 ≤ 0.70	5	89	0	35

Source: Field Survey data, 2016.

VIII. Conclusions

This study compares the technical efficiency scores estimated under the translog stochastic frontier production function model and the mathematical programming method for the CRS DEA and VRS DEA employing an output-oriented frontier approach for the cotton farmers in the Northeast zone, of Nigeria. The mean efficiency measure (0.91) obtained from the stochastic frontier is higher than that calculated from the VRS DEA (0.88) and that estimated from the CRS DEA (0.27). The efficiency results indicate that there is a 9–73% scope to increase cotton production with the existing technology and without additional inputs. The cotton farms seem to be characterized by strongly decreasing returns to scale under both the SFA and the DEA model, as confirm by the results of the scale efficiency in the models. The mean technical efficiency in the SFA is greater than that acquired from the DEA models. Perhaps the most important finding of this paper is that outlays for variable inputs used comprise an indisputable share in total costs of cotton production in the study area. In light of this research, this study suggests that government should intervene to subsidies farming implements for the benefit of the farmers.In addition, regular records and documentation by the extension argent at the farm level in the study areas should also be considered. Perhaps this restriction is one of the most important constraints in improving technical efficiencies in cotton farms and agricultural systems in general. Armagan and Nizam (2012) [15] stressed that to increase productivity and efficiency as well as to benefit from government subsidies, farms should keep their records regularly. This is because maintaining sufficient and regular records of cotton farms may be vital for optimum input and output management and to enhance efficiency at the farm level.

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