CHAPTER 6

COMPARISON OF RESULTS FROM ALTERNATIVE APPROACHES

6.1 Introduction

This chapter is concerned with the discussion of results from the different approaches employed in this study. The next section presents the frontier estimates and efficiency scores from the parametric stochastic input distance function (SIDF). In the third section, results of the frontier estimates and efficiency scores from the parametric stochastic production function (SFPF) are discussed. The efficiency scores from the non-parametric input distance function are presented in section four. A visual comparison of efficiency scores from the different frontier models are presented in section five. Formal tests are conducted and results of sensitivity of efficiency scores to estimation approaches are discussed in section six. In section seven, input usage ratio which depicts the nature of allocative efficiency is presented. In section eight, results of technology and policy impacts on efficiency from the various approaches are discussed and compared. The last section concludes on the chapter.

6.2 Parameter Estimates and Efficiency Scores from the SIDF Model

The maximum likelihood (ML) and the ordinary least square (OLS) estimates of the Cobb-Douglas SIDF are presented in table 6.1. A well behaved input distance function is non-decreasing in inputs and non-increasing in outputs, linearly homogeneous and concave in inputs (Coelli et al. 2005). Result shows that the estimated input distance function is well behaved with all input coefficients positive and output coefficient negative. All variables are significant at 1 percent. The estimated coefficient of output is less than one in absolute terms indicating increasing returns to scale which for the parametric stochastic input distance function is computed as the inverse of the negative of this value, which is 1.351 (Estache et al., 2004; Coelli et al., 2005). The partial output elasticity of land is 0.67 and is the largest among the inputs thereby depicting the importance of land in the household production. It implies that a 10 percent increase in land size would increase output by

6.7 percent. This finding confirms the observation of this study that the share of expenditure on land in the cost of production of sampled farmers is higher than those of other inputs. Land is the scarcest input and the high marginal returns to land are a reflection of the very small size of plot many farmers are constrained to cultivate. The second largest contributor to household production is labour with an elasticity of 0.23 implying that a 10 percent increase in labour supply will raise output by 2.3 percent. This is followed by the partial elasticity of other inputs (0.06) and fertilizer (0.04) implying that a 10 percent increase in other inputs and fertilizer will lead to 0.6 and 0.4 percent increase in output respectively.

Table 6.1: The OLS and maximum likelihood estimates of the SIDF

Variable	Mean	Parameter	OLS estimates	ML estimates
INTERCEPT		δ	3.718*** (0.200)	3.883*** (0.216)
PROD	1320.38	α	-0.729*** (0.021)	-0.740*** (0.021)
LAND	1.208	β_1	0.679*** (0.022)	0.667*** (0.024)
LAB	111.195	β_2	0.219*** (0.021)	0.233*** (0.023)
FERT	115.185	β_3	0.036*** (0.003)	0.038*** (0.003)
OTHER	56.343	β_4	0.067	0.061 [a]
SIGMA-SQUARED		$\sigma^2 = \sigma_u^2 + \sigma_v^2$		0.043*** (0.006)
GAMMA		$\gamma = \sigma_u^2 / \sigma^2$		0.825*** (0.060)
LLF			125.479	132.274

***Significant at 1% level. Standard errors are shown in parenthesis. [a] The estimate of β_4 is computed by the homogeneity condition

The estimate of the variance parameter, γ, is 0.83 and is significant at 1 percent implying that 83 percent of the total variation in output is due to inefficiency, that is, the technical inefficiency effects are significant in the stochastic input distance function. This result is confirmed by conducting a likelihood ratio test to test the hypothesis of OLS model versus input distance frontier model. LR test statistic is 13.23 and this was significant when compared with mixed chi-square value of 5.412 at one degree of freedom, thus rejecting the adequacy of the OLS model in representing the data.

Based on the estimated parameters of the stochastic input distance function, the parameters of the corresponding dual cost function were derived as specified in equation (4.42) and this formed the basis of computing the cost and allocative efficiency. The dual cost frontier is given as:

$$\ln C_i = -2.977 + 0.667\ln W_{Land} + 0.233\ln W_{Labour} + 0.038 W_{Fert} + 0.061\ln W_{Other} + 0.740\ln PROD_i \quad (5.1)$$

where C is the cost of production for the *i*th farmer. W_{Land} is the rental price of land per hectare estimated at ₦4989.17 . W_{Labour} is the price of labour per day estimated at ₦ 89.81. W_{Fert} is the price of inorganic NPK fertilizer per kg estimated at. ₦57.9. W_{Other} is implicit price index of other inputs estimated at ₦68.64 per kg. The derived cost function is equally well behaved.

The results of efficiency distributions and some descriptive statistics from the parametric stochastic input distance function are present in table 6.2. The results presented in this section are for the entire sample. Technical efficiency (TE) ranges from 64.3 to 97.1 with a mean of 86.7 percent. This implies that if farm households will operate on the frontier, they will achieve a cost savings of 13.3 percent without reducing output. On the other hand, if the average farm household in the sample was to achieve the TE level of its most efficient counterpart, then the average farm household could realize a 10.7 percent cost savings (i.e., 1–[86.7/97.1]). A similar calculation for the most technically inefficiency farm household reveals cost saving of 33.7 percent (i.e., 1– [64.3/97.1]).

The average allocative efficiency (AE) from the SIDF model is 57.8 percent with a low of 23 percent and a high of 88.8 percent. This implies that there is room to improve allocative efficiency of the farm households by 42.2 percent, if they operate on the frontier. It also suggests that if the average farm household was to achieve the AE level of its most efficient farm household, then the average farm household could achieve a cost saving of 34.9 percent while the least efficient farm household would achieve a cost saving of 74 percent.

Cost efficiency (CE) from the SIDF model ranges from 19.6 to 85.9 with a mean of 50.3 percent giving room for cost efficiency improvement by 49.7 percent, if farm households were to operate on the frontier and also suggests a gain economic efficiency of 41.5 percent for the average farm household and 77.2 percent for the least efficient farm household.

Table 6.2: Frequency distribution of efficiency estimates from SIDF model

Efficiency level (%)	TE		AE		CE	
	Number	Percent	Number	Percent	Number	Percent
≤ 40	0	0.00	21	8.75	55	22.92
41-50	0	0.00	37	15.42	59	24.58
51-60	0	0.00	68	28.33	73	30.42
61-70	14	5.83	84	35.00	44	18.33
71-80	29	12.08	28	11.67	8	3.33
81-90	111	46.25	2	0.83	1	0.42
91-100	86	35.83	0	0.00	0	0.00
Mean	86.7		57.8		50.3	
Min	64.3		23		19.6	
Max	97.1		88.8		85.9	
SD	7.6		11.9		12	
CV	8.8		20.5		23.9	

CV = coefficient of variation; Min = Minimum; Max = Maximum; SD = Standard deviation

6.3 Parameter Estimates and Efficiency Scores from the SFPF Model

The maximum likelihood (ML) and the ordinary least square (OLS) estimates of the Cobb-Douglas SFPF are presented in table 6.3. All the input coefficients in both models are positive as expected and statistically significant at 1 percent level implying that they contribute to increased output. The sum of the input coefficients is 1.136 indicating increasing returns to scale. This further implies that farmers are operating in the irrational stage of production. The partial output elasticity of land is 0.82 and is the largest among the inputs thereby depicting the importance of land in the household production. It implies that a 10 percent increase in land size would increase output by 8.2 percent. This finding confirms the observation of this study that the share of expenditure on land in the cost of production of sampled farmers is higher than those of other inputs. Land is the scarcest input and the high marginal returns to land are a reflection of the very small size of plot many farmers are constrained to cultivate. The contribution of land in the SFPF model is more than its contribution in the SIDF model. The second largest contributor to household production is labour with an elasticity of 0.19 implying that a 10 percent increase in labour supply will raise output by 1.9 percent. This contribution is low when compared to that of the SIDF model. The partial elasticity of other inputs (0.06) and fertilizer (0.05) are the least and these values are similar to the results from the SIDF model.

Table 6.3: The OLS and maximum likelihood estimates of the SFPF

Variable	Mean	Parameter	OLS estimates	MLE estimates
INTERCEPT		δ	5.623*** (0.140)	5.908*** (0.145)
LAND	1.208	β_1	0.820*** (0.031)	0.838*** (0.027)
LAB	111.195	β_2	0.216*** (0.029)	0.192*** (0.029)
FERT	115.185	β_3	0.048*** (0.004)	0.050*** (0.004)
OTHER	56.343	β_4	0.056*** (0.011)	0.056*** (0.010)
SIGMA-SQUARED		$\sigma^2 = \sigma_u^2 + \sigma_v^2$		0.067*** (0.009)
GAMMA		$\gamma = \sigma_u^2 / \sigma^2$		0.837*** (0.051)
LLF			72.044	81.100

***Significant at 1% level. Standard errors are shown in parenthesis.

The value of the parameter, γ, is 0.84 and is significant at 1 percent level implying that 84 percent of variation in output is due to inefficiency that is, the technical inefficiency effects are significant in the stochastic frontier production function. This result is confirmed by conducting a likelihood ratio test to test the hypothesis of OLS model versus production frontier model. LR test statistic is 18.11 and this was significant when compared with mixed chi-square value of 5.412 at one degree of freedom. Therefore, the traditional production function, with no technical inefficiency effects, that is the OLS model is not an adequate representation of the data.

Based on the estimated parameters of the stochastic frontier production function, the input ratios, and the adjusted observed output levels, the parameters of the corresponding dual cost function were derived and this formed the basis of computing the cost and allocative efficiency. The dual cost frontier is given as:

$$\ln C_i = -4.390 + 0.738 \ln W_{Land} + 0.169 \ln W_{Labour} + 0.044 W_{Fert} + 0.049 \ln W_{Other} + 0.740 \ln PROD_i \quad (5.2)$$

where C is the cost of production for the *i*th farmer. W_{Land} is the rental price of land per hectare estimated at ₦4989.17 . W_{Labour} is the price of labour per day estimated at ₦ 89.81. W_{Fert} is the price of inorganic NPK fertilizer per kg estimated at. ₦57.9. W_{Other} is implicit price index of other inputs estimated at ₦68.64 per kg. The derived cost function is well behaved.

The efficiency scores from the SFPF model is presented in table 6.4. Technical efficiency ranges from 43.3 to 99.7 with a mean of 85.3 percent. The presence of technical inefficiency indicates potential output gains without increasing input use. This implies that if farm households were to operate on the frontier, they will achieve a cost savings of 14.7 percent. On the other hand, if the average farm household in the sample was to achieve the TE level of its most efficient counterpart, then the average farm household could realize a 14.4 percent cost savings (i.e., 1–[85.3/99.7]). A similar calculation for the most technically inefficiency farm household reveals cost saving of 56.6 percent (i.e., 1– [43.3/99.7]).

The average allocative efficiency from the SFPF model is 52.6 percent with a low of 22.9 percent and a high of 79.9 percent. This implies that there is room to improve allocative efficiency of the farm households by 47.4 percent, if they operate on the frontier. It also suggests that if the average farm household was to achieve the AE level of its most efficient farm household, then the average farm household could achieve a cost saving of 34.2 percent while the least efficient farm household would achieve a cost saving of 71.3 percent.

Cost efficiency from the SFPF model ranges from 15.8 to 69.6 with a mean of 44.6 percent giving room for cost efficiency improvement by 55.4 percent, if farm households were to operate on the frontier and also suggests a gain economic efficiency of 35.9 percent for the average farm household and 77.3 percent for the least efficient farm household.

Table 6.4: Frequency distribution of efficiency estimates from SFPF model

Efficiency level (%)	TE		AE		CE	
	Number	Percent	Number	Percent	Number	Percent
≤ 40	0	0.00	34	14.17	88	36.67
41-50	1	0.42	77	32.08	72	30.00
51-60	2	0.83	67	27.92	70	29.17
61-70	27	11.25	48	20.00	10	4.17
71-80	51	21.25	14	5.83	0	0.00
81-90	73	30.42	0	0.00	0	0.00
91-100	86	35.83	0	0.00	0	0.00
Mean	85.3		52.6		44.6	
Min	43.3		22.9		15.8	
Max	99.7		79.9		69.6	
SD	10.7		11.9		10.8	
CV	12.5		22.6		24.2	

CV = coefficient of variation; Min = Minimum; Max = Maximum; SD = Standard deviation

6.4 Efficiency Scores from the Non-parametric Input Distance Models

The efficiency scores from the VRS DEA model are presented in table 6.5. Technical efficiency ranges from 51.5 to 100 with a mean of 85.5 percent. Thus, the most technically efficient farm household is operating on the frontier in this model. Therefore, if the average farm household in the sample was to achieve the TE level of its most efficient counterpart, then the average farm household could realize a 14.5 percent cost savings (i.e., 1–[85.5/100]) without reducing outputs. A similar calculation for the most technically inefficiency farm household reveals cost saving of 48.5 percent (i.e., 1– [51.5/100]).

The average allocative efficiency from the VRS DEA model is 73.8 percent with a low of 28.8 percent and a high of 100 percent. Again, the most allocatively efficient farm household is operating on the frontier. It suggests that if the average farm household was to achieve the AE level of its most efficient farm household, then the average farm household could achieve a cost saving of 26.2 percent while the least efficient farm household would achieve a cost saving of 71.2 percent.

Cost efficiency from the VRS DEA model ranges from 28.8 to 100 with a mean of 62.3 percent giving room for cost efficiency improvement by 37.7 percent on average and also suggests a gain economic efficiency of 71.2 percent for the least efficient farm household.

Table 6.5: Frequency distribution of efficiency estimates from VRS DEA model

Efficiency level (%)	TE		AE		CE	
	Number	Percent	Number	Percent	Number	Percent
≤ 40	0	0.00	13	5.42	21	8.75
41-50	0	0.00	11	4.58	34	14.17
51-60	11	4.58	24	10.00	46	19.17
61-70	22	9.17	45	18.75	72	30.00
71-80	58	24.17	50	20.83	46	19.17
81-90	51	21.25	60	25.00	16	6.67
91-100	98	40.83	37	15.42	5	2.08
Mean	85.5		73.8		62.3	
Min	51.5		28.8		28.8	
Max	100.0		100.0		100.0	
SD	12.9		16.7		14.6	
CV	15.1		22.6		23.4	

CV = coefficient of variation; Min = Minimum; Max = Maximum; SD = Standard deviation

The efficiency scores from the CRS DEA model are presented in table 6.6. Technical efficiency ranges from 37.5 to 100 with a mean of 80.1 percent. Thus, the most technically efficient farm household is operating on the frontier in this model. Therefore, if the average farm household in the sample was to achieve the TE level of its most efficient counterpart, then the average farm household could realize a 19.9 percent cost savings (i.e., 1–[80.1/100]) without reducing output. A similar calculation for the most technically inefficiency farm household reveals cost saving of 62.5 percent (i.e., 1– [37.5/100]).

The average allocative efficiency from the CRS DEA model is 65.9 percent with a low of 22.4 percent and a high of 100 percent. Again, the most allocatively efficient farm household is operating on the frontier. It suggests that if the average farm household was to achieve the AE level of its most efficient farm household, then the average farm household could achieve a cost saving of 34.1 percent while the least efficient farm household would achieve a cost saving of 77.6 percent.

Cost efficiency from the CRS DEA model ranges from 14.9 to 100 with a mean of 51.6 percent giving room for cost efficiency improvement by 48.4 percent on average and also suggests a gain economic efficiency of 85.1 percent for the least efficient farm household.

Table 6.6: Frequency distribution of efficiency estimates from CRS DEA model

Efficiency level (%)	TE		AE		CE	
	Number	Percent	Number	Percent	Number	Percent
≤ 40	1	0.42	28	11.67	68	28.33
41-50	20	8.33	37	15.42	57	23.75
51-60	7	2.92	28	11.67	37	15.42
61-70	42	17.50	34	14.17	58	24.17
71-80	49	20.42	46	19.17	12	5.00
81-90	49	20.42	49	20.42	5	2.08
91-100	72	30.00	18	7.50	3	1.25
Mean	80.1		65.9		51.6	
Min	37.5		22.4		14.9	
Max	100.0		100.0		100.0	
SD	15.8		19.2		15.6	
CV	19.7		29.1		30.2	

CV = coefficient of variation; Min = Minimum; Max = Maximum; SD = Standard deviation

6.5 A Visual Comparison of Efficiency Estimates from Different Frontier Models

From tables 6.3 to 6.6, maize farmers in Benue State operate with considerable inefficiency dominated by cost inefficiency as depicted by all approaches thereby providing an avenue for policy interventions that would help reduce inefficiency. It is observed that the estimated the technical, allocative and cost efficiency measures from the distance frontiers are greater than those from the production frontiers. In terms of technical efficiency, results from the parametric stochastic distance functions is better than those of other models, but in terms of allocative and cost efficiency , results from the non-parametric distance function is better. Similar results were obtained by Herrero (2005) for technical efficiency. No previous study has made comparison of allocative and cost efficiency from either parametric or non-parametric distance functions or from distance functions and production frontiers. In terms of variability, the efficiency scores from the parametric approach are less variable than those from the non-parametric approach. Specifically, the efficiency scores from the SIDF model are less variable than those from SFPF and DEA models whereas DEA models especially the CRS DEA model exhibited the greatest variability. The only similarity observed in terms of variability is in the allocative efficiency from VRS DEA and SFPF models. Results also show that no farm is one hundred percent efficient in the SIDF and SFPF models (ie. at the efficient frontier). This is due to the stochastic nature of the frontier; it allows for the possibility that part of the deviation of the observed output from the frontier may be due to noise or measurement errors. Results appear to imply that the best and worst performers can be identified reasonably well by any of the four models with respect to technical efficiency but the selection of a particular model with respect to allocative efficiency is not a trivial choice as the results are mixed.

Further, the comparison efficiency scores from different frontier models can be shown in their scatter plots. In this study, the scatter plot is used for two purposes namely: to show the correlation (if any) between and equality of any two set of efficiency scores. The scatter plot of technical efficiency estimates from SIDF and SFPF models is presented in figure 6.1. It can be deduced from the scatter plot that the TE values from these two models are not correlated and this is confirmed by the trend line which neither sloped upwards nor downwards. Similar results were obtained between VRS DEA and SFPF and between CRS DEA and SFPF TE scores as depicted in figures 6.4 and 6.5, respectively. TE scores from SIDF and the DEA models are positively correlated. Similar positive correlation is observed between TE scores from VRS DEA and CRS DEA models. Scatter plots of allocative and cost efficiency from different models are presented in figures 6.7 to 6.18. In all cases, positive correlation is observed though the degree varies between different models.

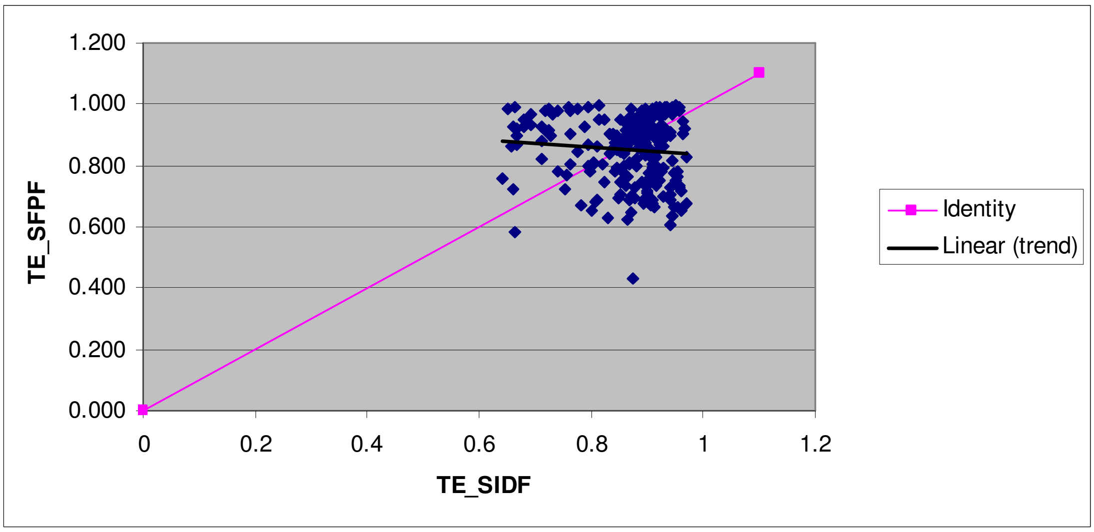

Figure 6.1: Scatter plot of technical efficiency from SIDF and SFPF models

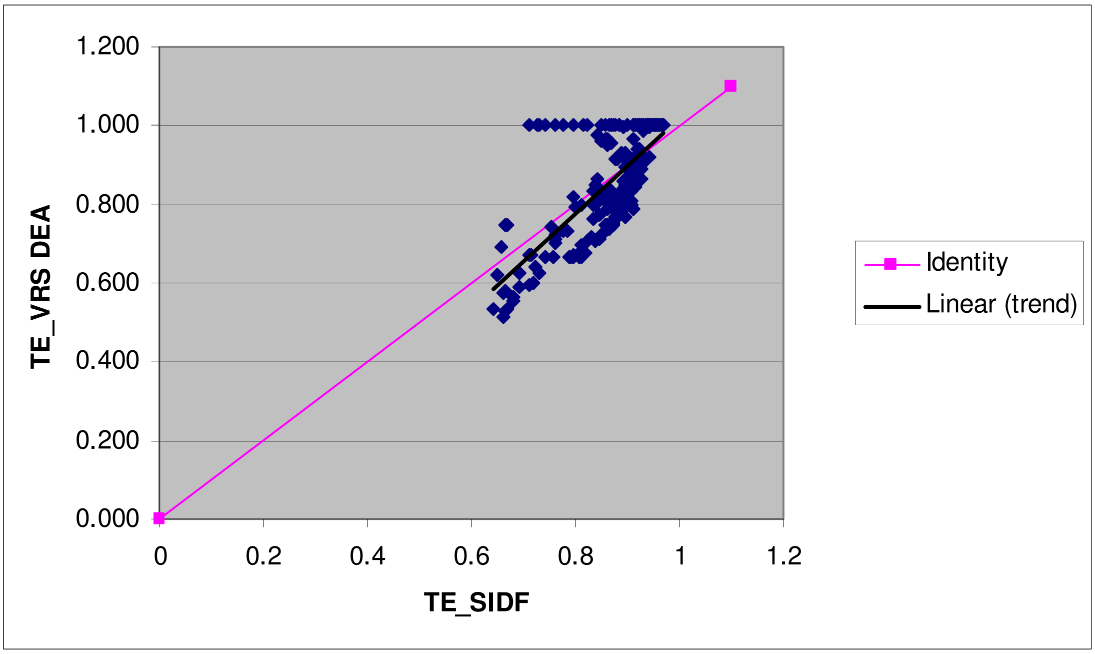

Figure 6.2: Scatter plot of TE from SIDF and VRS DEA models

In a scatter plot, an identity line, which is a 45^{o} line with the abscissa, is an easy means of showing the equality of two sets of data. The more the two data sets agree, the more the scatters tend to concentrate in the vicinity of the identity line; if the two data sets are numerically identical, the scatters fall on the identity line exactly. In all the scatter plots, no two sets of efficiency score scatters fall exactly on the identity line implying that no two frontier models produce identical results. However, figures 6.14 and 6.16 show a clear difference between the numerical values of cost efficiency scores from the two parametric approaches (SIDF and SFPF) and the non-parametric VRS DEA models.

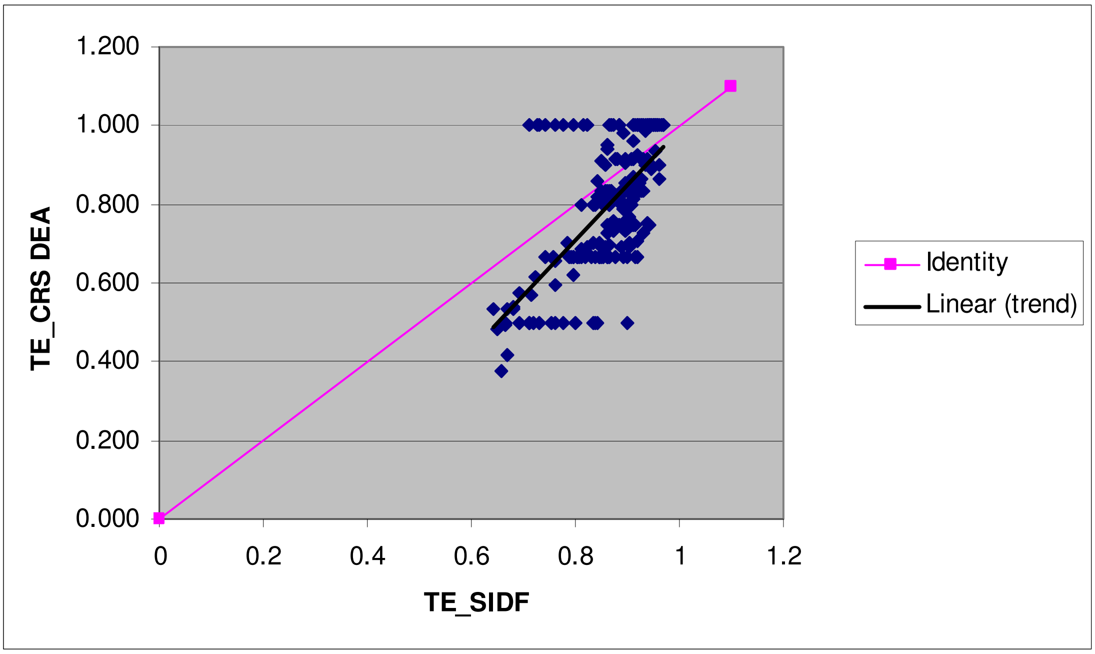

Figure 6.3: Scatter plot of TE from SIDF and CRS DEA models

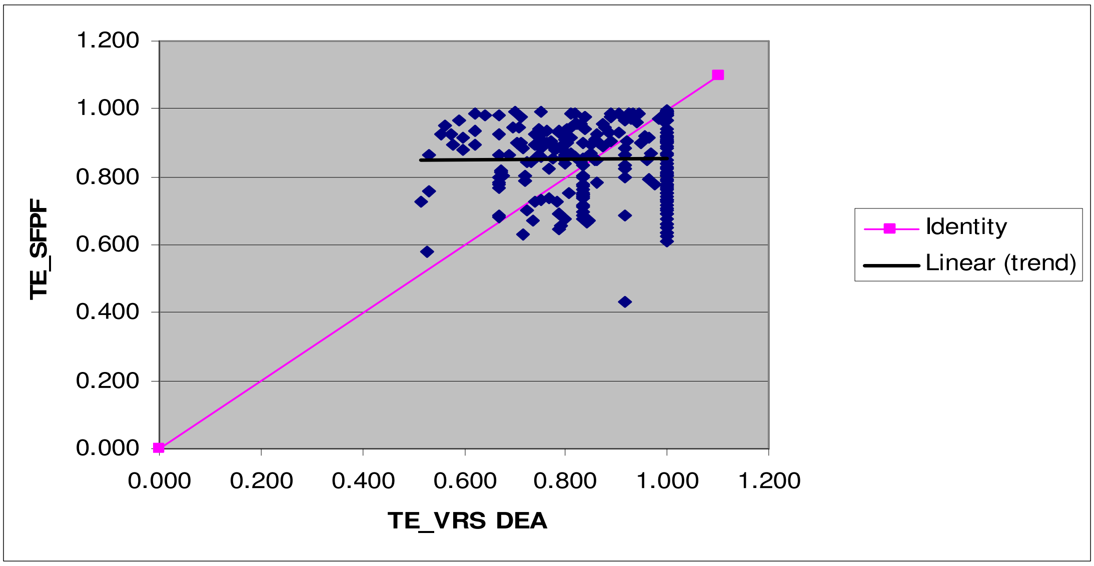

Figure 6.4: Scatter plot of TE from VRS DEA and SFPF models

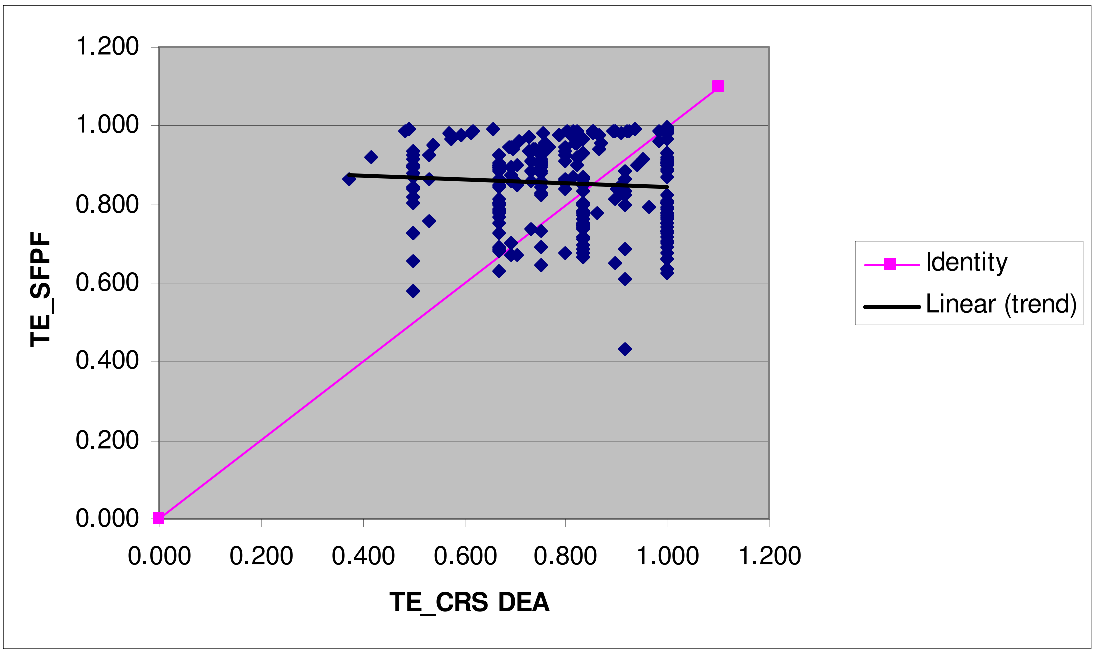

Figure 6.5: Scatter plot of TE from CRS DEA and SFPF models

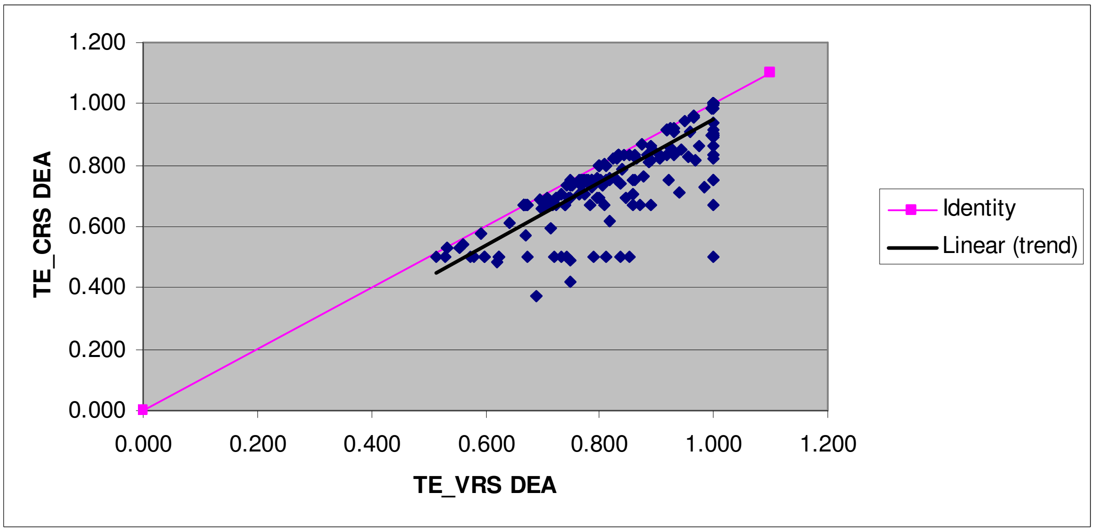

Figure 6.6: Scatter plot of TE from VRS and CRS DEA models

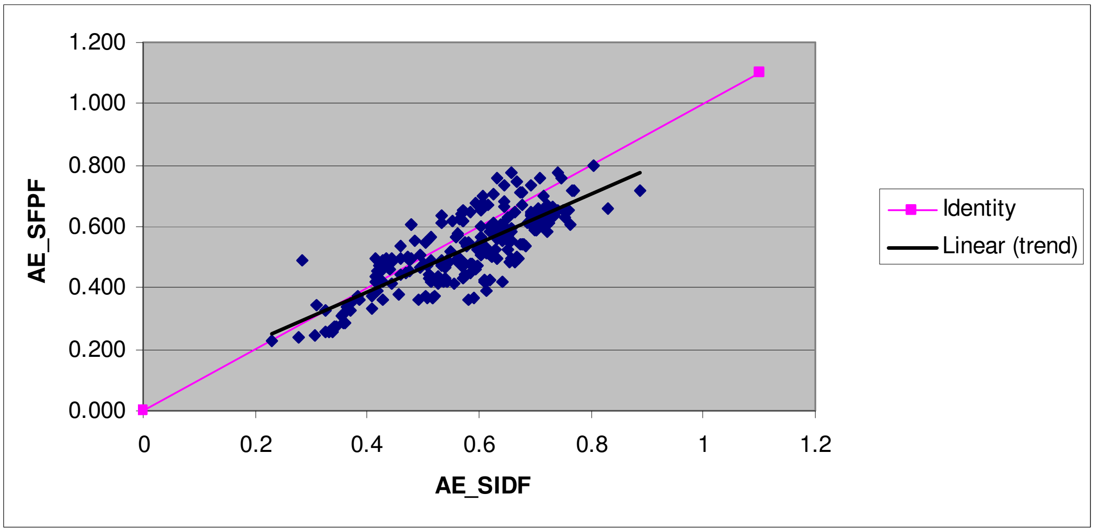

Figure 6.7: Scatter plot of allocative efficiency from SIDF and SFPF models

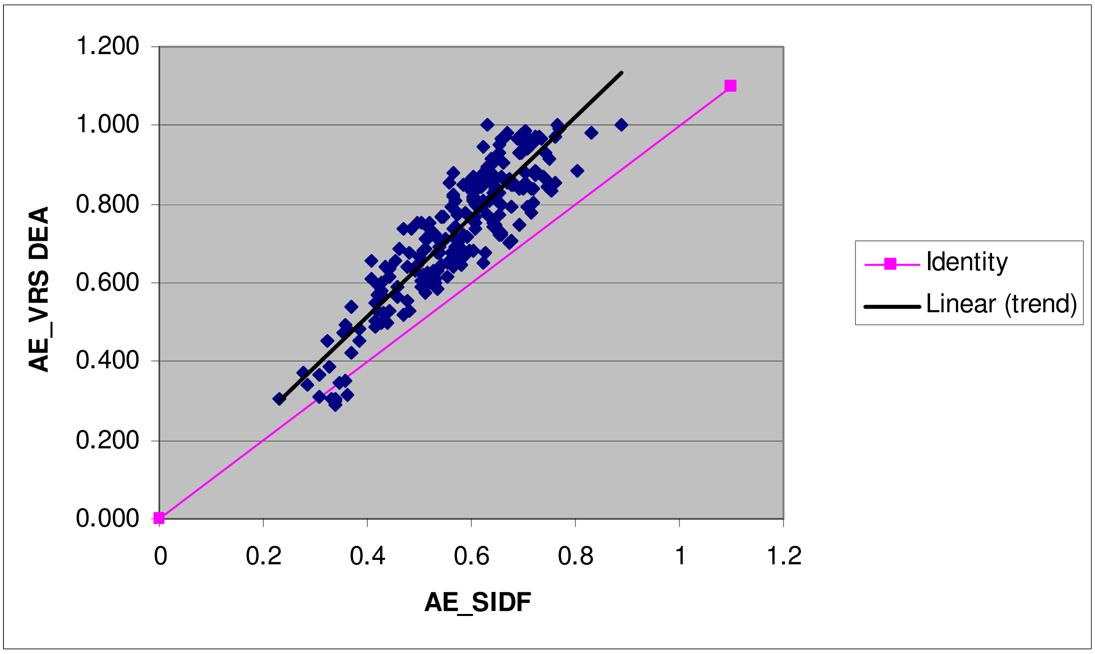

Figure 6.8: Scatter plot of AE from SIDF and VRS DEA models

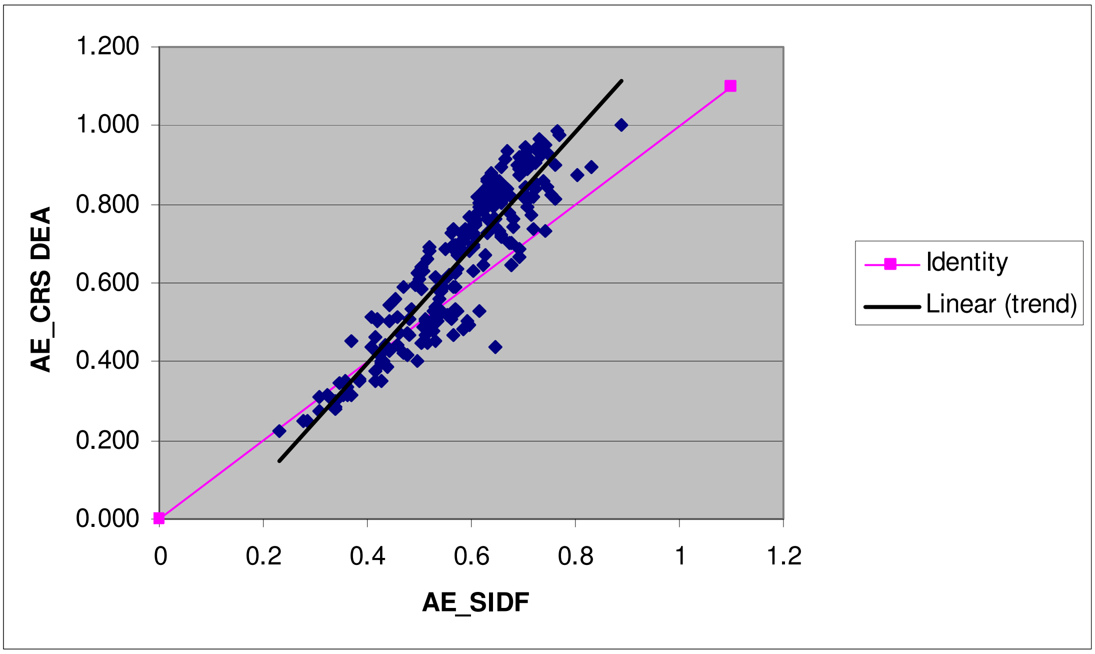

Figure 6.9: Scatter plot of AE from SIDF and CRS DEA models

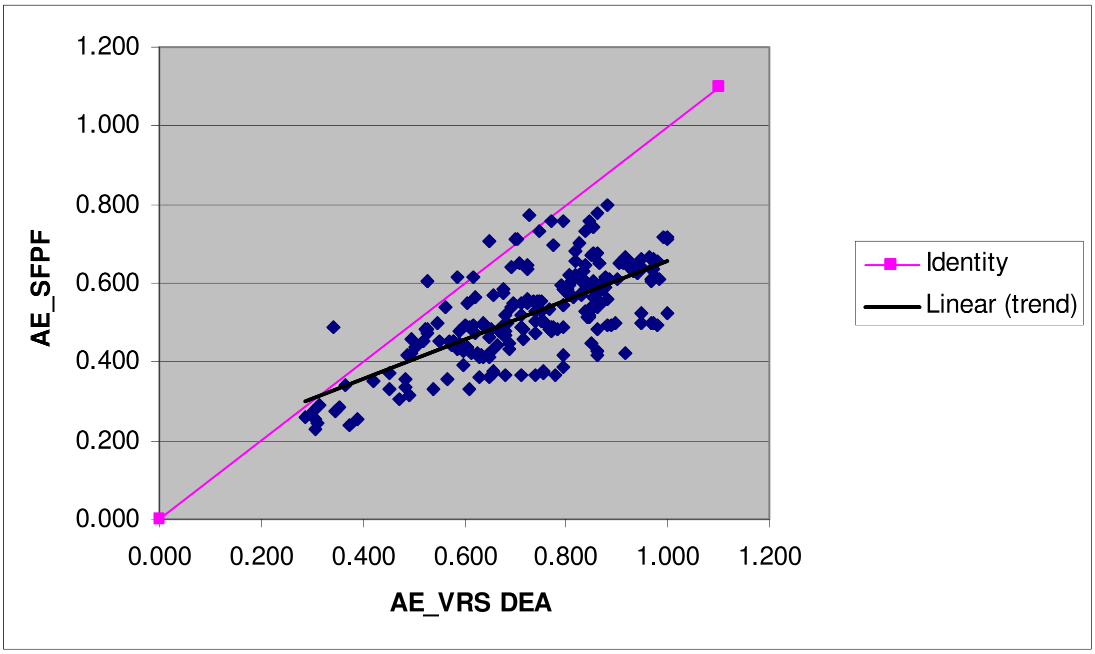

Figure 6.10: Scatter plot of AE from VRS DEA and SFPF models

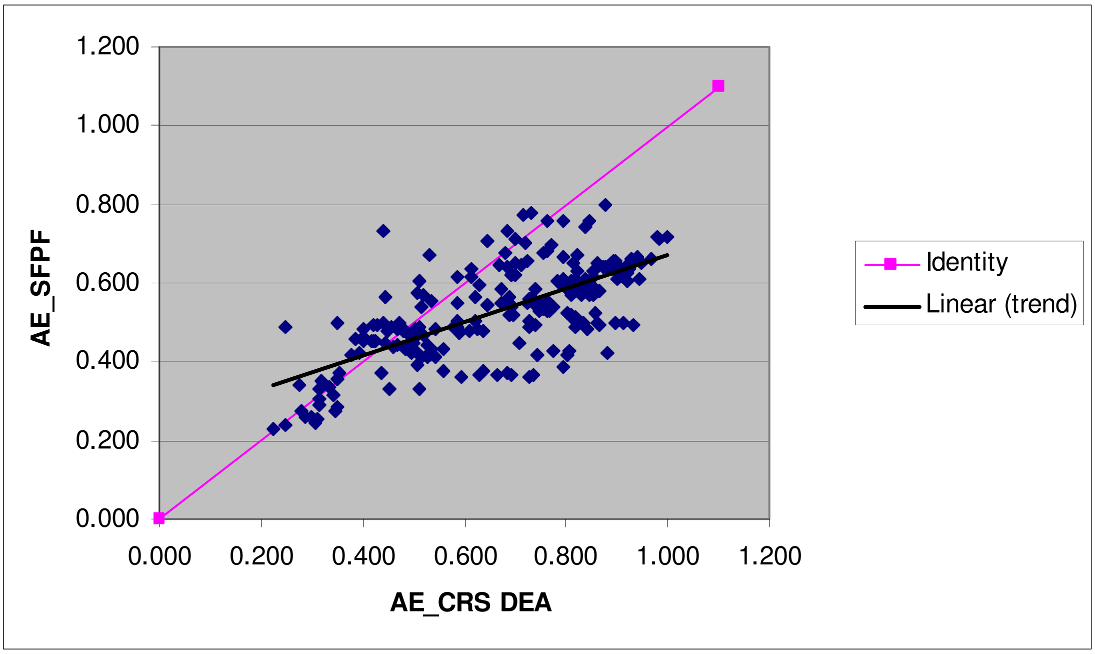

Figure 6.11: Scatter plot of AE from CRS DEA and SFPF models

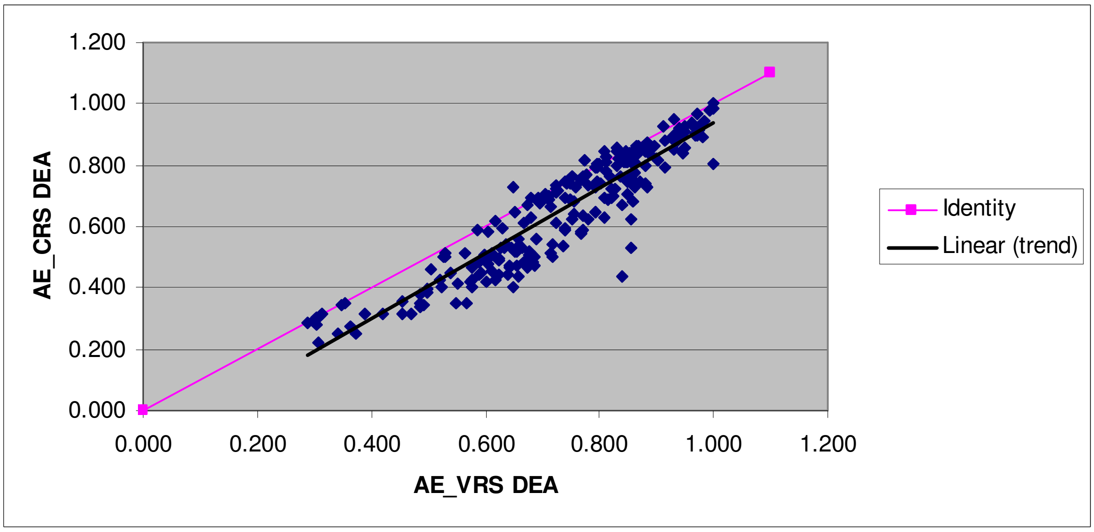

Figure 6.12: Scatter plot of AE from VRS and CRS DEA models

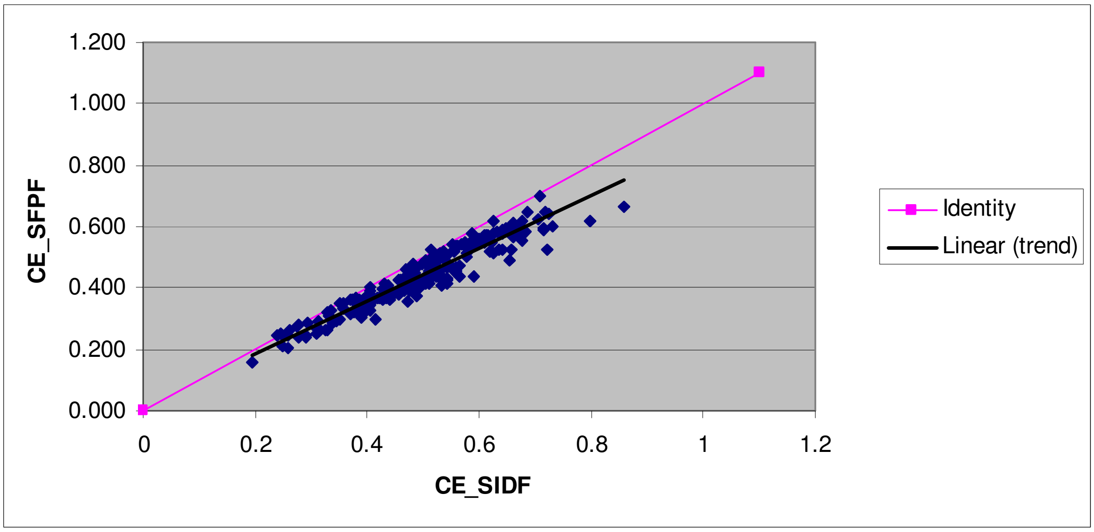

Figure 6.13: Scatter plot of cost efficiency from SIDF and SFPF models

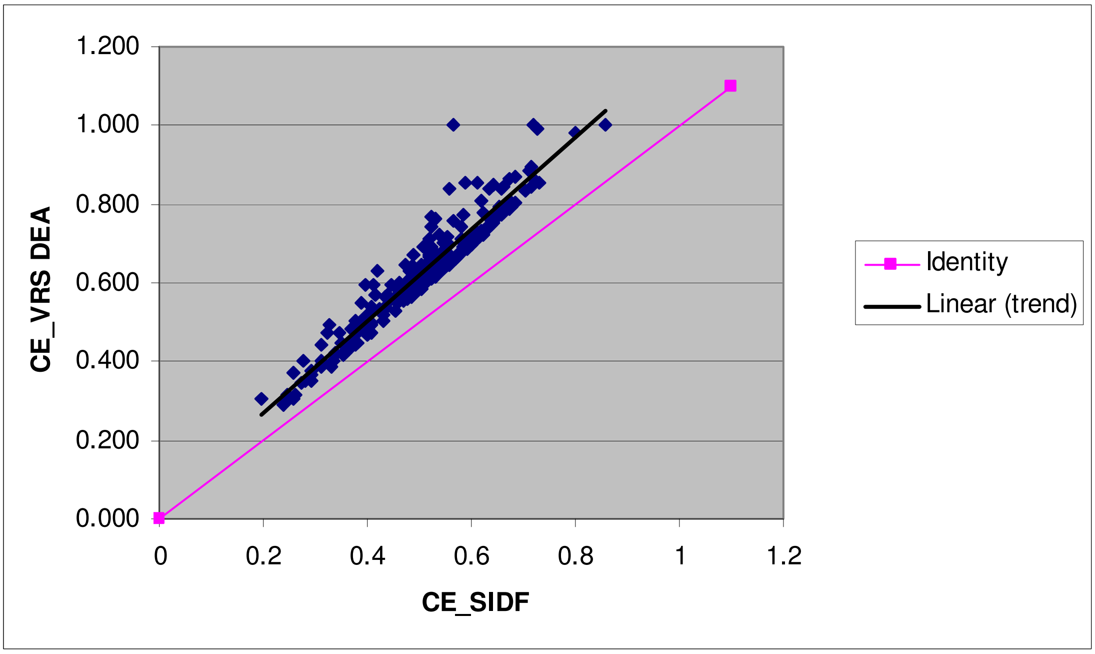

Figure 6.14: Scatter plot of CE from SIDF and VRS DEA models

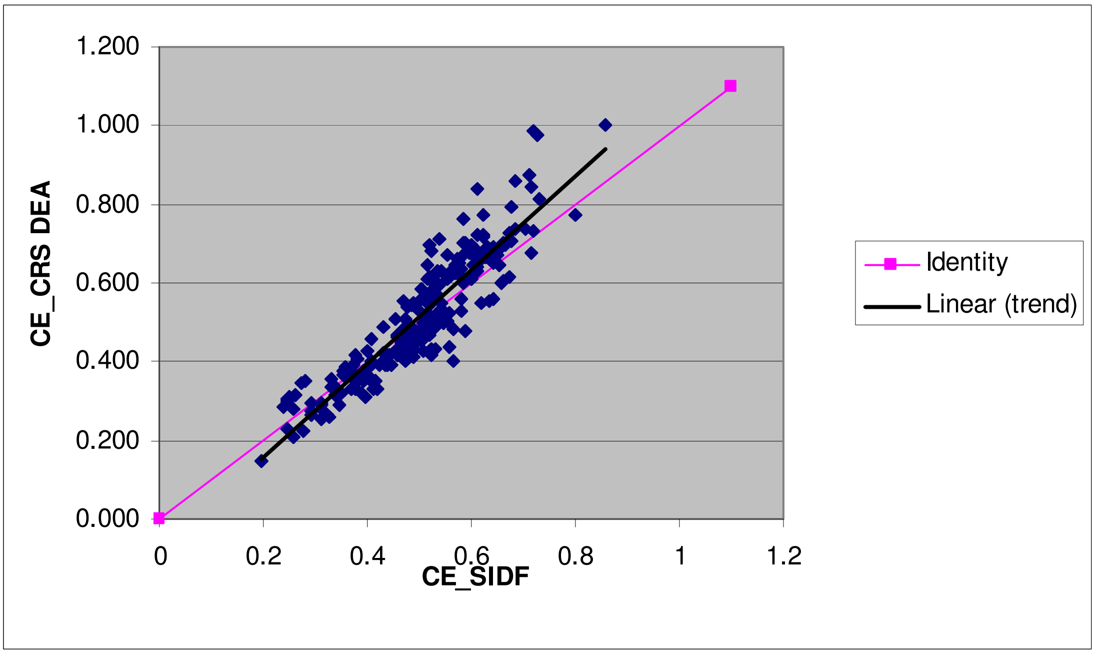

Figure 6.15: Scatter plot of CE from SIDF and CRS DEA models

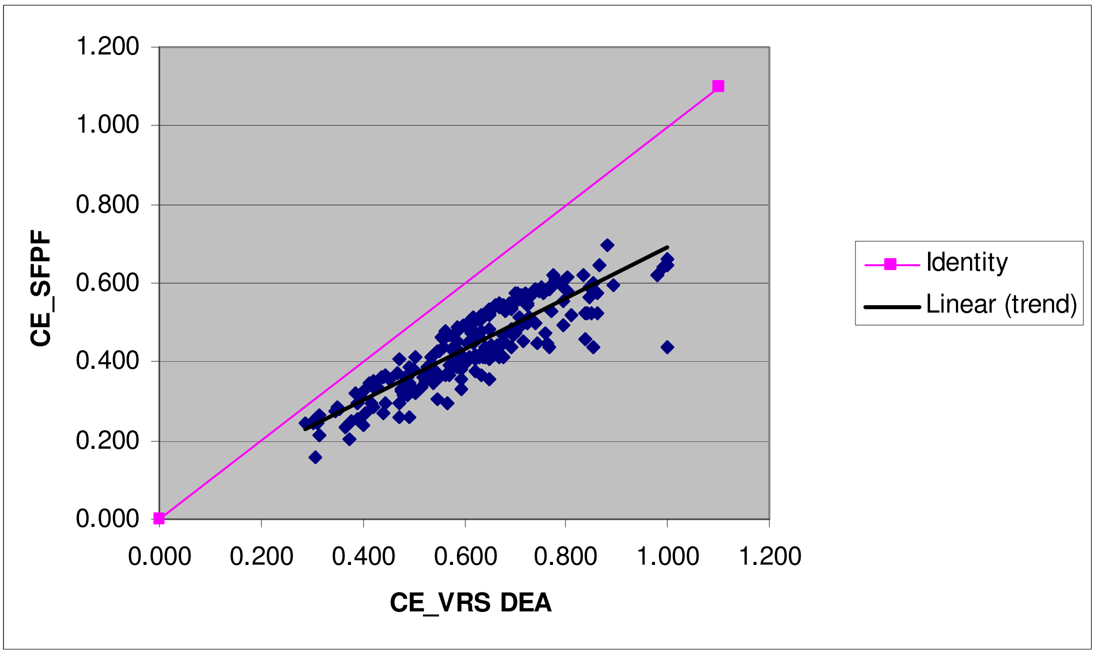

Figure 6.16: Scatter plot of CE from VRS DEA and SFPF models

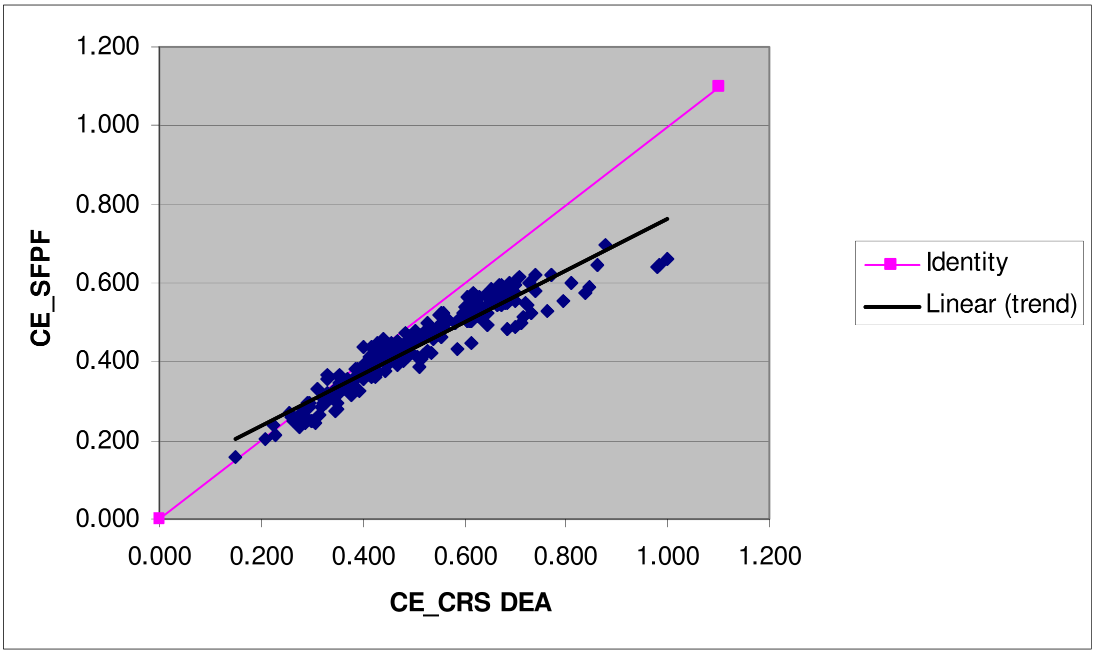

Figure 6.17: Scatter plot of CE from CRS DEA and SFPF models

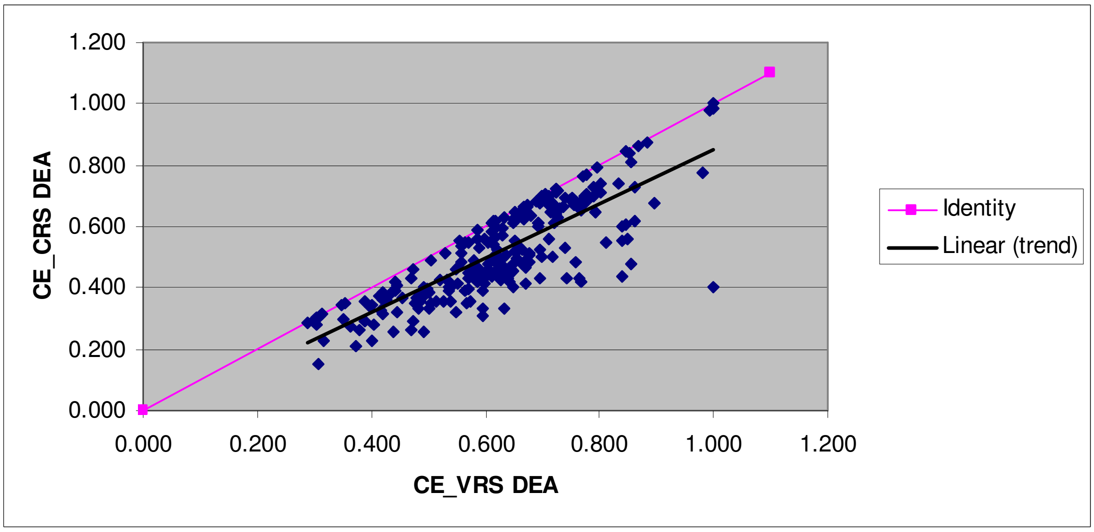

Figure 6.18: Scatter plot of CE from VRS and CRS DEA models

6.6 Sensitivity of Efficiency Scores to Estimation Approaches: Formal Tests

A problem faced by policy analysts to apply frontier studies is the variety of options at hand. The problem is particularly acute when the different approaches yield inconsistent results. Bauer et al. (1998) proposed a set of consistency conditions that if met, would make the choice of a particular approach trivial. The efficiency measures generated by the different techniques should show internal and external consistency: they should be consistent in their efficiency levels, rankings and identification of the best and worst performers and they should demonstrate reasonable stability. In the previous section a presentation of efficiency scores from different approaches was made without any test of hypothesis. However, to make a more concrete conclusion of this comparative study, formal tests of hypotheses are necessary. In this section, an evaluation of the statistical significance of the difference in efficiency scores generated by the different approaches is conducted. This is achieved by testing different complementary hypotheses relative to: (i) the equality of means (t-test), (ii) the equality of distributions (Wilcoxon signed rank-test), and (iii) the independence of the results with regard to their rank (Spearman's correlation test) which provides the evidence of overall consistency of results from different approaches.

The results of the t-test and Wilcoxon signed rank-test are presented in table 6.7 concluding that in the case of the t-tests, the differences between the technical, allocative and cost efficiency scores generated by SIDF and each of the DEA are statistically significant with a confidence of 95 percent. Also the difference between the SIDF and SFPF allocative and cost efficiency scores are statistically significant with a confidence of 95 percent but only marginally significant with respect to technically efficiency.

Table 6.7: Tests of hypothesis of the difference between efficiency means

Test	t-test[a] t-statistic			Wilcoxon test[b] Z-statistic		
	TE	**AE**	**CE**	**TE**	**AE**	**CE**
SIDF vs VRS DEA	2.133	-31.406	-39.925	2.936	-13.386	-13.431
	(0.034)	(0.000)	(0.000)	(0.003)	(0.000)	(0.000)
SIDF vs CRS DEA	8.606	-13.045	-3.044	7.900	-9.842	-2.356
	(0.000)	(0.000	(0.003)	(0.000)	(0.000)	(0.019)
SIDF vs SFPF	1.623	10.640	23.842	1.164	8.929	13.393
	(0.106)	(0.000)	(0.000)	(0.245)	(0.000)	(0.000)
VRS DEA vs SFPF	0.152	27.876	37.224	- 0.158	13.255	13.430
	(0.871)	(0.000)	(0.000)	(0.874)	(0.000)	(0.000)
CRS DEA vs SFPF	-4.125	14.905	16.941	-3.997	10.958	12.950
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

[a] H0 is the equality of means; [b] H0 is that both distributions are the same ; p-values in parenthesis

Further, the differences between the each of the DEA and SFPF technical, allocative and cost efficiency scores are statistically significant with a confidence of 95 percent with exception of the difference between technical efficiency scores from VRS DEA and SFPF which is not significant at any reasonable level. The Wilcoxon test further reinforces these results by indicating that the distributions of technical, allocative and cost efficiency estimates within the bilateral pairs of results are also statistically different with exception of technical efficiency results generated by SIDF and SFPF and VRS DEA and SFPF.

In addition to the test of differences in means, ANOVA was also conducted in order to test the hypothesis that variances of the efficiency scores generated by the four models (SIDF, SFPF, VRS DEA and CRS DEA) are the same against the alternative that at least two of them differ from one another. As the ANOVA test is parametric and therefore requires the population variances to be equal in the four models, the results derived from this test alone may not be valid. Therefore, the Kruskal-Wallis test which is non-parametric was also carried out. It does not require any assumptions regarding the normality or variances of the populations. These results are reported in table 6.8. At the 5 percent level of significance, these tests reject the null hypothesis in favour of the alternative. These results further strengthen the findings from table 6.7.

Table 6.8: Tests of hypothesis of the difference between efficiency variances

Test	TE	AE	CE
ANOVA (F-statistic)	14.19 (0.000)	90.13 (0.000)	72.44 (0.000)
Kruskal-Wallis (χ^2 statistic)	21.749 (0.000)	216.118 (0.000)	171.837 (0.000)

Note: p-values in parenthesis

Although, the different approaches produced efficiency measures that are quantitatively different from each other with exception of the technical efficiency results from VRS DEA and SFPF, it is still possible to achieve consistency of results with respect to ranking of individual farm households which in many policy analysis may be more important than the quantitative estimates of efficiency. Therefore, to assess the overall consistency of the three methods in ranking individual farms in terms of efficiency, the coefficient of Spearman rank-order correlation was calculated for each efficiency measure. Results are presented in table 6.9. The Spearman's rank correlation coefficients for allocative and cost efficiency from all the four models are positive and highly significant suggesting that the different farm household rank similarly when they are ordered according to either their parametric and non-parametric allocative and cost efficiency scores. Similar result is obtained for technical efficiency scores from both the parametric and non-parametric distance

Table 6.9 Spearman's rank correlations among efficiency scores

	SIDF	VRS DEA	CRS DEA	SFPF
Technical Efficiency				
SIDF	1.000	0.705 ***	0.654***	-0.020
VRS DEA		1.000	0.871***	0.023
CRS DEA			1.000	-0.040
SFPF				1.000
Allocative Efficiency				
SIDF	1.000	0.872***	0.902***	0.772***
VRS DEA		1.000	0.929***	0.669***
CRS DEA			1.000	0.674***
SFPF				1.000
Cost Efficiency				
SIDF	1.000	0.963***	0.927***	0.957***
VRS DEA		1.000	0.836***	0.883***
CRS DEA			1.000	0.960***
SFPF				1.000

*** Significantly different from zero at 5% level

functions, suggesting that the different farm household rank similarly when they are ordered according to either their parametric and nonparametric distance function technical efficiency scores. The findings with respect to technical efficiency are consistent with that of Cuesta et al. (2009). However, the Spearman's rank correlation results between technical efficiency scores from the distance frontiers and production frontiers are very low and not statistically significant.

6.7 Input Usage Ratios

The mean allocative efficiency reported for each of the models indicates that some inputs are being used in incorrect proportions. To check for over-utilization or under-utilization of the production inputs by farmers, the ratio of technically efficient input quantity over the cost-efficient input quantity (for each observation) is calculated from each of the frontier models. The means of these ratios are presented in table 6.10. The results show that given the respective market prices of the various inputs, fertilizer is consistently under-utilized, labour is consistently over-utilized, land is under-utilized in most cases whereas results of other inputs are mixed. Therefore, for the farmers to operate efficiently, the use of fertilizer and land needs to be increased whereas the use of labour needs to be contracted.

Table 6:10: Input usage ratios of maize farmers in Benue State

Models	Land	Labour	Fertilizer	Other inputs
SIDF	0.61	2.86	0.46	4.71
SFPF	0.72	5.20	0.63	0.10
VRS	0.98	1.34	0.40	1.61
CRS DEA	1.21	1.81	0.98	0.88

6.8 Technological Innovation and Efficiency: Comparison of Alternative Models

A major goal of this section is to evaluate the impact of technological innovation on farm efficiency. Two approaches are followed here. First, a t-test of difference in means of technical, allocative and cost efficiency generated from each model for adopters and non-adopters of each technology was conducted. Second, an empirical evidence of the direction and magnitude of the impact of technological innovations and other policy variables on farm efficiency is provided in a second stage Tobit regression after testing and correcting for endogeniety. The test of difference in the mean technical efficiency for improved and traditional maize farm households are presented in table 6.11. Results show that for the hybrid seed, the null hypothesis of equality in average technical efficiency were rejected at 5 percent level in all the four models implying that farm households who adopted hybrid seed were more technically efficient than those who did not and this conclusion is robust to different approaches employed for the analysis. This is reasonable as use of hybrid seed is expected to enhance yield thus bringing the farmers closer to the frontier. Farm households who used fertilizer were significantly less efficient than those who did not as shown by the non-parametric models. One could have taught that it may be the case that the farmers either applied the fertilizer wrongly or below recommended rates but since these may apply to all farmers, the only explanation could be as a result of algorithm used in estimating the technical efficiency. In most cases, households who used herbicides for weed control on their maize farms were significantly more technically efficient than those who did not use. Results further show that farm households who adopted conservation practices on their maize farms were consistently and significantly more technically efficient in all the distance frontier models.

Table 6.11: Technical efficiency estimates and test of difference in means for traditional versus improved maize farmers

	HYV			
Improved:	SIDF	VRS DEA	CRS DEA	SFPF
Mean	0.887	0.874	0.822	0.885
Min.	0.650	0.556	0.483	0.433
Max.	0.971	1.000	1.000	0.997
SD	0.058	0.111	0.144	0.091
Traditional:				
Mean	0.794	0.782	0.721	0.845
Min.	0.643	0.515	0.375	0.581
Max.	0.958	1.000	1.000	0.994
SD	0.092	0.166	0.182	0.109
t-ratio	8.816	4.643	4.179	2.381
	AFERT			
Improved:	SIDF	VRS DEA	CRS DEA	SFPF
Mean	0.866	0.847	0.793	0.851
Min.	0.643	0.515	0.375	0.433
Max.	0.971	1.000	1.000	0.997
SD	0.078	0.129	0.159	0.108
Traditional:				
Mean	0.888	0.972	0.912	0.888
Min.	0.843	0.864	0.816	0.663
Max.	0.950	1.000	1.000	0.992
SD	0.040	0.037	0.077	0.092
t-ratio	-1.111	-3.718	-2.873	-1.313
	HERB			
Improved:	SIDF	VRS DEA	CRS DEA	SFPF
Mean	0.884	0.869	0.827	0.819
Min.	0.643	0.515	0.500	0.433
Max.	0.971	1.000	1.000	0.994
SD	0.068	0.124	0.142	0.111
Traditional:				
Mean	0.838	0.829	0.754	0.913
Min.	0.650	0.556	0.375	0.693
Max.	0.963	1.000	1.000	0.997
SD	0.081	0.135	0.173	0.065
t-ratio	4.721	2.302	3.515	-7.282
	PRACTICES			
Improved:	SIDF	VRS DEA	CRS DEA	SFPF
Mean	0.899	0.890	0.839	0.867
Min.	0.712	0.597	0.500	0.608
Max.	0.971	1.000	1.000	0.994
SD	0.047	0.105	0.132	0.104
Traditional:				
Mean	0.812	0.792	0.734	0.845
Min.	0.643	0.515	0.375	0.433
Max.	0.965	1.000	1.000	0.997
SD	0.086	0.144	0.177	0.108
t-ratio	10.128	6.037	5.220	1.538

For allocative efficiency, results of the t-test are presented in table 6.12. The results show that allocative efficiency of farm households who used hybrid seed were not statistically different from those who did not except in the SFPF model where results show that farm households who adopted hybrid seeds were more allocatively efficient

Table 6.12: Allocative efficiency estimates and test of difference in means for traditional versus improved maize farmers

	HYV			
Improved:	SIDF	VRS DEA	CRS DEA	SFPF
Mean	0.580	0.739	0.657	0.540
Min.	0.230	0.304	0.224	0.229
Max.	0.888	1.000	1.000	0.799
SD	0.121	0.164	0.193	0.118
Traditional:				
Mean	0.569	0.735	0.669	0.473
Min.	0.337	0.288	0.287	0.257
Max.	0.763	0.973	0.940	0.669
SD	0.111	0.180	0.186	0.107
t-ratio	0.591	0.154	-0.388	3.608
	AFERT			
Improved:	SIDF	VRS DEA	CRS DEA	SFPF
Mean	0.580	0.745	0.670	0.530
Min.	0.230	0.288	0.224	0.229
Max.	0.888	1.000	1.000	0.799
SD	0.122	0.170	0.192	0.121
Traditional:				
Mean	0.547	0.637	0.490	0.460
Min.	0.502	0.588	0.445	0.412
Max.	0.596	0.716	0.534	0.565
SD	0.032	0.036	0.029	0.040
t-ratio	1.035	2.447	3.627	2.241
	HERB			
Improved:	SIDF	VRS DEA	CRS DEA	SFPF
Mean	0.569	0.725	0.639	0.543
Min.	0.230	0.288	0.224	0.229
Max.	0.888	1.000	1.000	0.777
SD	0.126	0.167	0.193	0.119
Traditional:				
Mean	0.593	0.762	0.696	0.496
Min.	0.306	0.301	0.299	0.245
Max.	0.830	1.000	0.984	0.799
SD	0.103	0.166	0.184	0.113
t-ratio	-1.497	-1.638	-2.235	2.952
	PRACTICES			
Improved:	SIDF	VRS DEA	CRS DEA	SFPF
Mean	0.590	0.746	0.661	0.551
Min.	0.278	0.364	0.249	0.238
Max.	0.888	1.000	1.000	0.777
SD	0.117	0.152	0.191	0.110
Traditional:				
Mean	0.555	0.725	0.655	0.481
Min.	0.230	0.288	0.224	0.229
Max.	0.803	0.984	0.966	0.799
SD	0.119	0.190	0.194	0.121
t-ratio	2.250	0.950	0.231	4.567

than non-adopters. Farm households who adopted the fertilizer technology were consistently more allocatively efficient than those who did not in all the four models and this difference is significant at 5 percent level except in the SIDF model. Whereas the SFPF model shows that households who used herbicides for weed control were

Table 6.13: Cost efficiency estimates and test of difference in means for traditional versus improved maize farmers

	HYV			
Improved:	SIDF	VRS DEA	CRS DEA	SFPF
Mean	0.515	0.639	0.529	0.454
Min.	0.196	0.304	0.149	0.158
Max.	0.859	1.000	1.000	0.696
SD	0.117	0.142	0.158	0.109
Traditional:				
Mean	0.455	0.560	0.463	0.417
Min.	0.240	0.288	0.287	0.243
Max.	0.731	0.854	0.812	0.601
SD	0.121	0.144	0.136	0.101
t-ratio	3.200	3.494	2.698	2.148
	AFERT			
Improved:	SIDF	VRS DEA	CRS DEA	SFPF
Mean	0.504	0.623	0.520	0.449
Min.	0.196	0.288	0.149	0.158
Max.	0.859	1.000	1.000	0.696
SD	0.124	0.150	0.160	0.111
Traditional:				
Mean	0.486	0.620	0.447	0.406
Min.	0.433	0.541	0.391	0.374
Max.	0.555	0.716	0.534	0.454
SD	0.040	0.047	0.046	0.028
t-ratio	0.556	0.079	1.780	1.515
	HERB			
Improved:	SIDF	VRS DEA	CRS DEA	SFPF
Mean	0.505	0.624	0.520	0.444
Min.	0.196	0.288	0.149	0.158
Max.	0.859	1.000	1.000	0.662
SD	0.127	0.151	0.163	0.113
Traditional:				
Mean	0.498	0.621	0.508	0.451
Min.	0.246	0.301	0.292	0.245
Max.	0.799	1.000	0.984	0.696
SD	0.107	0.136	0.143	0.099
t-ratio	0.440	0.145	0.572	- 0.487
	PRACTICES			
Improved:	SIDF	VRS DEA	CRS DEA	SFPF
Mean	0.531	0.658	0.546	0.465
Min.	0.257	0.364	0.208	0.206
Max.	0.859	1.000	1.000	0.662
SD	0.111	0.132	0.157	0.105
Traditional:				
Mean	0.453	0.560	0.463	0.414
Min.	0.196	0.288	0.149	0.158
Max.	0.714	0.883	0.876	0.696
SD	0.120	0.148	0.140	0.106
t-ratio	5.082	5.265	4.086	3.569

more allocatively efficient than those who did not, the SIDF, VRS and DEA models depict that farm households who used were less efficient than those who did not and these results are statistically significant. It could be that although herbicides were used by some of the farm households, the quantity used was not optimal as to produce a greater allocative efficiency. The allocative efficiency of farm households who adopted conservation practices on their farms was consistently higher than those who did not. However, this observation was only significant in the SIDF and SFPF models.

Results of the t-test results for cost efficiency are reported in table 6.13. Households who adopted hybrid seeds were more cost efficient than those who did not and this is robust to all the approaches. Although, hybrid seed are more costly than local seeds, but yields from hybrid seed is more and therefore the per unit cost is less compared to local seed. Cost efficiency levels are more for households who used fertilizers than those who did not but this is only significant in the CRS DEA model.

Households who used herbicides are more cost efficient than those who did not though this is not significant. Finally households who used conservation practices are more cost efficient than those who did not and results from all the models were statistically significant. Again, one can argue that although, conservation practices are an addition to production cost, but the yield benefit arising from improvement in soil quality reduces per unit cost when compared to non-use. From these tests, one can argue for more public investment in development and diffusion of improved maize technologies especially hybrid maize seed and conservation technologies as these could improve productivity and food security without endangering environmental sustainability.

For direction and magnitude of impact of technological innovation on efficiency, an endogeneity-corrected Tobit model is employed in the second step regression. Summary results for the Smith and Blundell (1986) test of exogeneity of the technological innovation variables is presented in table 6.14. The test was conducted in two steps. In the first step, each potential endogenous variable is estimated with OLS over a set of instruments and the exogenous variables of the Tobit model. In the second step, the predicted residual from the OLS regression is included as an additional explanatory variable and the revised Tobit model is estimated. If the coefficient of the predicted residual is found not to be statistically significant, then the potential endogenous variable is treated as exogenous. However, if the null hypothesis of exogeniety is rejected, then the potential endogenous variable is truly endogenous and its predicted value is included in a second step as additional explanatory variable which yields unbiased estimates of impact of technological innovation on efficiency.

The exogeneity test is repeated for TE, AE and CE cases. TE, AE and CE are different endogenous variables having different values and distributions; therefore it will be wrong to assume that because a particular technology variable is found endogenous in the TE case, it will also be found endogenous in the AE and CE cases. This is proved later in the test results.

Table 6.14: Summary result of Smith-Blundell test of exogeneity

Model	Predicted Residuals			
	RES_HYV	**RES_AFERT**	**RES_HERB**	**RES_PRACTICES**
SIDF:				
TE	0.023** (0.012)	-0.025 (0.016)	-0.016 (0.014)	-0.005** (0.002)
AE	-0.113*** (0.024)	-0.056* (0.033)	-0.041 (0.029)	-0.002 (0.011)
CE	-0.088*** (0.022)	-0.088*** (0.022)	-0.050* (0.027)	-0.004 (0.010)
VRS DEA:				
TE	0.160*** (0.041)	0.003 (0.052)	0.092* (0.049)	0.012 (0.016)
AE	-0.140***(0.041)	-0.027 (0.054)	-0.030 (0.048)	-0.003 (0.017)
CE	-0.043 (0.029)	-0.025 (0.038)	-.009 (0.034)	-0.002 (012)
CRS DEA:				
TE	0.236*** (0.049)	-0.002 (0 .060)	0.045 (0.057)	0.012 (0.019)
AE	-0.198*** (0.041)	-0.043 (0.055)	-0.055 (0.050)	-0.008 (0.018)
CE	-0.063*** (0.024)	-0.058** (0.029)	-0.058** (.027)	-0.008 (0.010)
SFPF:				
TE	-0.083*** (0.025)	0.046 (0.033)	0.051* (0 .028)	-0.005 (0.011)
AE	-0.039 (0.025)	-0.092*** (0 .031)	-0.097*** (0.028)	-0.002 (0 .011)
CE	-0.076*** (0 .020)	-0.057** (0.026)	-0.056** (0.023)	-0.007 (0.009)

***Significant at 1% level; **significant at 5% level; *significant at 10% level. Standard errors are shown in parenthesis.

It is noted that the exogeniety of hybrid seed was rejected in all cases except for allocative and cost efficiency in the SFPF and VRS DEA models, respectively. The exogeniety of conservation practices was rejected in only one case, which is in the SIDF technical efficiency model. In all cases where exogeneity is rejected, the analysis is conducted using predicted values of the endogenous variables.

Tables 6.15 through 6.17 reports the results of the determinants of technical efficiency, allocative efficiency and cost efficiency measures estimated from SIDF, VRS DEA, CRS DEA and SFPF models. The tables include the estimated coefficients and their statistical significance, standard errors and significance level. In addition, the tables report the value of the log-likelihood function, its significance, and finally, the log-likelihood ratio test for each model. In order to assess the causality of technology and household characteristics on efficiency, including a comparison between the models, each estimated coefficient was reported and compared by model. The significance of the likelihood ratio (LR) test in each model implies the joint significance of all variables included in the model. Thus, the hypothesis that the technology and other policy variables included in the model have no significant impact on efficiency is rejected in all the models.

The effect of AGE on efficiency could be ambiguous, depending on whether older farmers are more experienced or more likely to stick to farming traditions and less likely to adopt new technologies. AGE has a positive sign and significant impact on technical efficiency in all the four models but significant on cost efficiency in only the VRS DEA model. Thus, the variable indexes experience and serve as a proxy for human capital showing that farmers with greater farming experience will have better management skills and thus higher efficiency than younger farmers. Increased farming experience may lead to better assessment of the importance and complexity of good farming decision, including efficient use of farming inputs. The positive and significant impact of age is consistent with the findings of Khai et al. (2008).

The second human capital variable, EDU was consistently positive though has significant impact on only the technical efficiency case in all the four models. Similar positive and significant impact of education on technical efficiency of maize farmers in Nigeria was found by Oyewo and Fabiyi (2008). The result is also consistent with that of Wadud and White (2000) and Alene (2003). The lack of significance of education for allocative and cost efficiency may be due to the low average education level of about eight years, depicting a generally non-completion of junior secondary school in the study area. This finding is not strange as similar results were found by Coelli et al. (2002) and Haji (2006).

HHS was found to be positively and significantly related to technical and cost efficiency in all the models with exception of the VRS DEA model. These finding indicates the importance of abundant labour supply especially for labour intensive farming. A possible explanation is that the labour variable in our study dominated by family labour assists in producing maximal output at the least cost since it reduces the need to hire labour. Moreover, a larger household size guarantees availability of family labour for farm operations to be accomplished in time.

The variable LAND is aimed at capturing the effect of scale production on the technical efficiency of the farm. A review by Lundvall and Battese (2000) establish a varied relationship between farm size and technical inefficiency in developing countries using the frontier production function. In this study, we observe that the relationship between LAND and the three efficiency measures in all the models are inconsistent. However, in most cases where it was found statistically significant, it had a positive sign with exception of its relationship with technical efficiency in the SIDF model which was negative and significant. The inverse relationship in the technical efficiency case agrees with the findings of Peterson (1997); Msuya (2008) and Okoye et al., 2006, 2009. The relatively consistent positive and significant relationship in the allocative and cost efficiency measures implies that farmers with larger farm sizes are more efficient in choosing cost-minimizing input combinations and these results are consistent with the findings of Karagiannis et al. (2000). However, there is need for caution in the interpretation of these findings given the contrasting results. A similar contrasting relationship between land and technical, allocative and cost efficiency was found by Coelli et al. (2002) for modern boro rice farmers in Bangladesh, India.

The variable OFFWORK is included to capture the effect of off-farm work on efficiency. The effect of this variable could be ambiguous. While on the one hand, it increases the income base of the farm household thus helping them to overcome credit and insurance constraints and increase their use of industrial inputs. On the other hand, it reduces the labour available for agricultural production especially if hiring agricultural labour incurs transaction costs and if hired labour is not as efficient as family labour (Feng, 2008). In this study, OFFWORK was consistently negative in all the four models but has significant impact on technical efficiency in the SIDF and VRS DEA models only. This implies that farmers who engage in off-farm work are likely to be less efficient in farming as they share their time between farming and other income-generating activities. Productivity suffers when any part of production is neglected. This finding is consistent with that of Mariano et al. (2010).

Table 6.15: Tobit model results of impact of technological innovation on TE

	SIDF	VRS DEA	CRS DEA	SFPF	
Variable	Coeff.	Coeff.	Coeff.	Coeff.	Mean
GENDER	-0.013	-0.037	-0.044	-0.017	0.888
	(0.009)	(0.030)	(0.034)	(0.018)	
AGE	0.002***	0.004***	0.004***	0.002***	47.167
	(0.000)	(0.001)	(0.001)	(0.001)	
EDU	0.002***	0.004**	0.004***	0.002*	8.433
	(0.000)	(0.001)	(0.002)	(0.001)	
HHS	0.001***	0.000	0.003*	0.002***	11.742
	(0.000)	(0.001)	(0.001)	(0.001)	
LAND	-0.034***	0.071**	0.152***	0.098***	1.208
	(0.008)	(0.029)	(0.034)	(0.018)	
OFFWORK	-0.010*	-0.037*	-0.025	-0.000	0.675
	(0.006)	(0.020)	(0.023)	(0.012)	
MFG	0.045***	0.059*	0.111***	0.009	0.454
	(0.010)	(0.033)	(0.037)	(0.021)	
EXT	-0.003**	0.002	-0.005	0.005	2.546
	(0.002)	(0.006)	(0.006)	(0.003)	
CREDIT	0.023***	0.044	0.025	0.059***	0.138
	(0.008)	(0.028)	(0.032)	(0.017)	
MARKET	-0.000	-0.003*	-0.002	-0.002**	6.278
	(0.000)	(0.002)	(0.002)	(0.001)	
HYV	0.011**	0.024	0.038*	0.010	0.895
	(0.006)	(0.020)	(0.022)	(0.012)	
AFERT	0.018**	0.029	0.027	0.025	0.816
	(0.009)	(0.029)	(0.035)	(0.017)	
HERB	0.008	0.000	0.054**	-0.048***	0.591
	(0.006)	(0.014)	(0.025)	(0.009)	
PRACTICES	0.009***	0.024***	0.018**	0.005	1.75
	(0.002)	(0.007)	(0.008)	(0.004)	
INTERCEPT	0.750***	0.592***	0.400***	0.726***	
	(0.019)	(0.065)	(0.074)	(0.040)	
LLF	417.474	38.538	32.413	241.167	
LR TEST	293.72***	104.400***	106.510***	101.970***	

***Significant at 1% level; **significant at 5% level; *significant at 10% level. Standard errors are shown in parenthesis

Table 6.16: Tobit model results of impact of technological innovation on AE

	SIDF	VRS DEA	CRS DEA	SFPF	
Variable	Coeff.	Coeff.	Coeff.	Coeff.	Mean
GENDER	0.012	0.011	0.019	0.016	0.888
	(0.019)	(0.032)	(0.032)	(0.018)	
AGE	-0.000	0.001	-0.002	0.001	47.167
	(0.001)	(0.001)	(0.001)	(0.001)	
EDU	0.000	0.001	0.002	0.001	8.433
	(0.001)	(0.002)	(0.002)	(0.001)	
HHS	0.001	0.001	0.001	0.003	11.742
	(0.001)	(0.001)	(0.001)	(0.001)	
LAND	0.045**	-0.003	0.072**	0.012	1.208
	(0.020)	(0.030)	(0.030)	(0.020)	
OFFWORK	-0.005	-0.003	-0.002	-0.007	0.675
	(0.013)	(0.021)	(0.021)	(0.012)	
MFG	0.002	0.019	0.041	0.031	0.454
	(0.021)	(0.035)	(0.035)	(0.020)	
EXT	0.007*	0.007	0.009	-0.002	2.546
	(0.004)	(0.006)	(0.006)	(0.003)	
CREDIT	0.129***	0.170***	0.176***	0.075***	0.138
	(0.018)	(0.029)	(0.029)	(0.017)	
MARKET	-0.000	-0.001	-0.001	-0.001	6.278
	(0.001)	(0.002)	(0.002)	(0.001)	
HYV	0.034***	0.046**	0.063***	0.027**	0.895
	(0.013)	(0.021)	(0.021)	(0.011)	
AFERT	0.057**	0.078**	0.107***	0.098***	0.816
	(0.027)	(0.032)	(0.032)	(0.025)	
HERB	-0.014	-0.030	-0.031	0.023***	0.591
	(0.013)	(0.023)	(0.022)	(0.008)	
PRACTICES	0.002	0.002	0.002	0.001	1.75
	(0.005)	(0.008)	(0.008)	(0.004)	
INTERCEPT	0.431***	0.689***	0.501***	0.359***	
	(0.041)	(0.068)	(0.069)	(0.039)	
LLF	234.686	112.307	113.035	246.962	
LR TEST	139.09***	66.090***	122.850***	163.400***	

***Significant at 1% level; **significant at 5% level; *significant at 10% level. Standard errors are shown in parenthesis.

Table 6.17: Tobit model results of impact of technological innovation on CE

	SIDF	VRS DEA	CRS DEA	SFPF	
Variable	Coeff.	Coeff.	Coeff.	Coeff.	Mean
GENDER	0.000	-0.010	-0.007	0.003	0.888
	(0.017)	(0.022)	(0.017)	(0.015)	
AGE	0.001	0.001**	0.001	0.000	47.167
	(0.001)	(0.001)	(0.001)	(0.001)	
EDU	0.001	0.001	0.001	0.000	8.433
	(0.001)	(0.001)	(0.001)	(0.001)	
HHS	0.001*	0.001	0.002***	0.001*	11.742
	(0.001)	(0.001)	(0.001)	(0.001)	
LAND	0.025	0.036*	0.123***	0.055	1.208
	(0.018)	(0.021)	(0.018)	(0.016)	
OFFWORK	-0.009	-0.018	-0.012	-0.004	0.675
	(0.012)	(0.015)	(0.012)	(0.010)	
MFG	0.028	0.027	0.039***	0.027*	0.454
	(0.019)	(0.025)	(0.019)	(0.017)	
EXT	0.004	0.007*	0.002	0.001	2.546
	(0.003)	(0.004)	(0.003)	(0.003)	
CREDIT	0.130***	0.177***	0.131***	0.101***	0.138
	(0.016)	(0.021)	(0.016)	(0.014)	
MARKET	-0.000	0.001	-0.001	-0.001	6.278
	(0.001)	(0.001)	(0.001)	(0.001)	
HYV	0.035***	0.018	0.035***	0.032***	0.895
	(0.011)	(0.014)	(0.011)	(0.010)	
AFERT	0.060***	0.053**	0.091***	0.065***	0.816
	(0.024)	(0.023)	(0.024)	(0.021)	
HERB	-0.005	-0.019	0.008	-0.004	0.591
	(0.008)	(0.016)	(0.008)	(0.007)	
PRACTICES	0.006	0.010*	0.007*	0.003	1.75
	(0.004)	(0.005)	(0.004)	(0.004)	
INTERCEPT	0.305***	0.388***	0.163***	0.256	
	(0.038)	(0.047)	(0.038)	(0.033)	
LLF	259.949	194.421	258.991	291.303	
LR TEST	196.07***	168.110***	318.070***	207.520***	

***Significant at 1% level; **significant at 5% level; *significant at 10% level. Standard errors are shown in parenthesis.

Membership in a farmer group (MFG) indexes social capital and affords the farmers opportunity of sharing information on modern maize practices by interacting with others as well as provides farmers with bargaining power in the input, output and credit markets. As expected, MFG was found to be consistently positive. It has significant impact on technical efficiency in almost all the models. It also has significant impact on cost efficiency in the CRS DEA and SFPF models. The positive and significant impact is consistent with the findings of Ogunyinka and Ajibefun (2004).

The extension variable, EXT, is expected to be positive as it enhances farmers' access to information and improved technological packages. However the impact of the extension variable is mixed. It was however found to have negative and significant impact on technical efficiency in the SIDF model, positive and significant impact on allocative efficiency in the same model, positive and significant impact on cost efficiency in the VRS DEA model. Some researchers (Okoye et al., 2006, Ogunyinka and Ajibefun, 2004) in Nigeria have found similar negative sign of the extension variable for technical efficiency. This finding is consistent with the findings of Feeder et al. (2004); Binam et al. (2004); Rahman (2004); Haji (2006) and Demircan et al. (2010). Each of these studies involved farmers in developing countries. The inability to find the correct sign and statistical significance has been attributed to the bureaucratic inefficiency, the deficiency in program design, (Feeder et al., 2004; Binam et al., 2004) and the use of a "top-down" instead of participatory approach (Braun et al., 2002). This negative impact can be explained by the fact that extension services in Nigeria in general has not been effective, especially after the withdrawal of World Bank funding from the Agricultural Development Project (ADP), which is the main agency responsible for extension services. Given this problem of inadequate funding of the extension outfit, dissemination of agricultural innovation to farmers are done in most cases at wrong periods and farmers do not have access to yield improving inputs at the right time. More so, when extension agents do not have new information for farmers, contact with extension agents would only amount to a waste of resources leading to negative impact.

CREDIT is consistently positive and significant in most cases with exception of its impact on technical efficiency in the VRS and CRS DEA models. This is as expected since the availability of credit loses the production constraints thus facilitating timely purchase of inputs and therefore increases productivity via efficiency. The result is consistent with the findings of Muhammad (2009) but contrast with that of Haji (2006) who rather found a negative though not significant impact of credit access to technical, allocative and cost efficiency.

The variable MARKET was included to capture farmers' access to market. It serves as a proxy for the development of road and market infrastructures. It is generally believed that farms located closer to the market are more technically, allocatively and economically efficient than the farms located farther from the market as this might not only increase production cost but also affect farming operations, especially the timing of input application. This expectation was satisfied in this study as the MARKET variable was correctly signed in most cases but it only had significant impact on technical efficiency in the VRS DEA and SFPF models. GENDER was never significant in any of the models and the signs were mixed.

Finally, an important goal of this study is to evaluate explicitly the impact of technological innovation on efficiency of maize farmers using results from different frontier approaches. Although improve technologies will generally raise production cost in absolute terms, the yield enhancement arising from their usage can reduce per unit cost of production thereby raising not only technical efficiency but cost efficiency as well. Results show that HYV has positive and significant impact on technical, allocative and cost efficiency in almost all the models. Chirwa (2007) employed a production frontier model and found a positive and significant impact of hybrid seed use on technical efficiency of smallholder maize farmers in Malawi. Similar impact of improved maize seed on cost efficiency from a cost frontier model was reported in Zavale et al. (2006). These findings further strengthen the need for hybrid seed improvement and diffusion in Nigeria in line with the current doubling of maize production programme of the federal government.

AFERT have positive and significant impact on technical efficiency in the SIDF model only but positive and significant impact on allocative and cost efficiency in all the four models. The findings are consistent with that of Okoye et al. (2006) and Msuya et al. (2008) who found a positive impact of inorganic fertilizer on allocative and technical efficiency, respectively. The fertilizer technology can be said to corroborate to credit. Thus, failure to use fertilizer may result in irretrievable output loss.

The sign of the variable, HERB, is mixed. Whereas it has positive and significant impact on technical and allocative efficiency in the CRS DEA and SFPF models, respectively, it has negative and significant effect on allocative efficiency in the SFPF model. The dominating negative sign of herbicides could be due to the farmers' perception of the health and environmental effects of herbicides coupled with its high cost and inadequate application knowledge, which constrained its adoption and usage. PRACTICES have positive impact on all the efficiency measures in all the models though this impact is only significant for technical and cost efficiency. This is expected because the use of conservation practices improves land quality and hence yield as well as reduces the unit cost of production. This finding is consistent with that of Solis et al. (2009) who found a positive and significant impact of conservation practices on technical efficiency of peasant farmers in Central America. According to Otsuki et al. (2002) many rural policies in Latin America have been conceived to promote economic development but usually have had costly environmental effects. However, the findings in this study support the hypothesis that the adoption of soil conservation practices is not only a good tool for controlling environmental degradation but is also associated with higher farm efficiency. Thus, economic and environmental sustainability can be viewed as complementary rather than competitive goals.

The marginal effects are also reported in tables 6.18 through 6.20. There are three options for estimating marginal effects namely (1) The marginal effects for the probability of the dependent variable (technical, allocative or cost efficiency) being uncensored, (2) the marginal effects for the expected value of the dependent variable conditional on being uncensored and, (3) the marginal effect effects for the unconditional expected value of the dependent variable. These three options were employed. It is however, noted that the coefficients and marginal effects are numerically similar due to the fact that there are relatively small number of censored observations especially in the SFPF and SIDF models. Thus, only results of option 2 are presented.

As to the interpretation of the marginal effects, using the results of the SIDF model and hybrid seed variable for example, the marginal effect of 0.011 for HYV on technical efficiency shows that, for the sample period, an increase in the area cultivated with hybrid seed by 100 percent would lead, on average to an increase in technical efficiency by 11 percent. The marginal effect of 0.034 for HYV on technical efficiency shows that, for the sample period, an increase in the area cultivated with hybrid seed by 100 percent would lead, on average to an increase in allocative efficiency by 34 percent. Similarly, cost efficiency will increase by 35 percent on average, for a 100 percent increase in the area cultivated with HYV. Similar interpretations hold for all variables in all the three efficiency measures.

Table 6.18: Marginal effects for the expected value of technical efficiency

	SIDF	VRS DEA	CRS DEA	SFPF	
Variable	Marginal Effects	Marginal Effects	Marginal Effects	Marginal Effects	Mean
GENDER	-0.013	-0.021	-0.028	-0.013	0.888
	(0.009)	(0.016)	(0.021)	(0.014)	
AGE	0.002***	0.002***	0.002***	0.001***	47.167
	(0.000)	(0.001)	(0.001)	(0.001)	
EDU	0.002***	0.002**	0.003***	0.001*	8.433
	(0.000)	(0.001)	(0.001)	(0.001)	
HHS	0.001***	0.000	0.002*	0.002***	11.742
	(0.000)	(0.001)	(0.001)	(0.001)	
LAND	-0.033***	0.042***	0.102***	0.080***	1.208
	(0.008)	(0.017)	(0.023)	(0.015)	
OFFWORK	-0.010*	-0.021*	-0.016	-0.000	0.675
	(0.006)	(0.012)	(0.015)	(0.010)	
MFG	0.044***	0.035*	0.073***	0.007	0.454
	(0.010)	(0.019)	(0.025)	(0.017)	
EXT	-0.003**	0.001	-0.003	0.004	2.546
	(0.002)	(0.003)	(0.004)	(0.003)	
CREDIT	0.022	0.024*	0.017	0.045***	0.138
	(0.008)	(0.015)	(0.022)	(0.012)	
MARKET	-0.000	0.002*	-0.001	-0.002**	6.278
	(0.000)	(0.001)	(0.001)	(0.001)	
HYV	0.011**	0.015	0.026*	0.008	0.895
	(0.006)	(0.012)	(0.015)	(0.010)	
AFERT	0.018**	0.017	0.018	0.021	0.816
	(0.009)	(0.017)	(0.023)	(0.014)	
HERB	0.008	0.000	0.036**	-0.039***	0.591
	(0.006)	(0.008)	(0.017)	(0.007)	
PRACTICES	0.009***	0.014***	0.012**	0.004	1.75
	(0.002)	(0.004)	(0.005)	(0.004)	

***Significant at 1% level; **significant at 5% level; *significant at 10% level. Standard errors are shown in parenthesis.

Table 6.19: Marginal effects for the expected value of allocative efficiency

Variable	SIDF Marginal Effects	VRS DEA Marginal Effects	CRS DEA Marginal Effects	SFPF Marginal Effects	Mean
GENDER	0.012	0.009	0.018	0.016	0.888
	(0.019)	(0.027)	(0.030)	(0.018)	
AGE	0.000***	0.001	0.001	0.001	47.167
	(0.001)	(0.001)	(0.001)	(0.001)	
EDU	0.000	0.001	0.002	0.001	8.433
	(0.001)	(0.001)	(0.001)	(0.001)	
HHS	0.001	0.001	0.001	0.003***	11.742
	(0.001)	(0.001)	(0.001)	(0.001)	
LAND	0.045**	-0.003	0.067**	0.012	1.208
	(0.020)	(0.025)	(0.028)	(0.020)	
OFFWORK	-0.005	-0.002	-0.002	-0.007	0.675
	(0.013)	(0.018)	(0.020)	(0.012)	
MFG	0.002	0.016	0.038	0.031	0.454
	(0.021)	(0.030)	(0.033)	(0.020)	
EXT	0.007*	0.006	0.009	-0.002	2.546
	(0.004)	(0.005)	(0.006)	(0.003)	
CREDIT	0.129***	0.123***	0.149***	0.075***	0.138
	(0.018)	(0.018)	(0.022)	(0.017)	
MARKET	-0.000	-0.001	-0.001	-0.001	6.278
	(0.001)	(0.001)	(0.002)	(0.001)	
HYV	0.034***	0.039**	0.058***	0.027**	0.895
	(0.013)	(0.017)	(0.019)	(0.011)	
AFERT	0.057***	0.065***	0.099***	0.098***	0.816
	(0.027)	(0.027)	(0.030)	(0.025)	
HERB	-0.014	-0.025	0.029	0.023***	0.591
	(0.013)	(0.019)	(0.021)	(0.008)	
PRACTICES	0.002	0.002	0.002	0.001	1.75
	(0.005)	(0.006)	(0.007)	(0.004)	

***Significant at 1% level; **significant at 5% level; *significant at 10% level. Standard errors are shown in parenthesis

Table 6.20: Marginal effects for the expected value of cost efficiency

	SIDF	VRS DEA	CRS DEA	SFPF	
Variable	Marginal Effects	Marginal Effects	Marginal Effects	Marginal Effects	Mean
GENDER	0.000	-0.009	-0.007	0.003	0.888
	(0.017)	(0.022)	(0.017)	(0.015)	
AGE	0.001	0.001	0.001	0.000	47.167
	(0.001	(0.001)	(0.001)	(0.001)	
EDU	0.001	0.001	0.001	0.000	8.433
	(0.001)	(0.001)	(0.001)	(0.001)	
HHS	0.001*	0.001	0.002***	0.001*	11.742
	(0.001)	(0.001)	(0.001)	(0.001)	
LAND	0.025	0.025	0.123***	0.055***	1.208
	(0.018)	(0.021)	(0.018)	(0.016)	
OFFWORK	-0.009	-0.016	-0.012	-0.004	0.675
	(0.012)	(0.015)	(0.012)	(0.010)	
MFG	0.028	0.025	0.039***	0.027*	0.454
	(0.019)	(0.025)	(0.019)	(0.017)	
EXT	0.004	0.007*	0.002	0.001	2.546
	(0.003)	(0.004)	(0.003)	(0.003)	
CREDIT	0.130***	0.171***	0.131***	0.101***	0.138
	(0.016)	(0.019)	(0.016)	(0.014)	
MARKET	-0.000	0.000	-0.001	-0.001	6.278
	(0.001)	(0.001)	(0.001)	(0.001)	
HYV	0.035***	0.031**	0.035***	0.032***	0.895
	(0.011)	(0.014)	(0.011)	(0.010)	
AFERT	0.060***	0.054**	0.091***	0.065***	0.816
	(0.024)	(0.022)	(0.024)	(0.021)	
HERB	-0.005	-0.019	0.008	-0.004	0.591
	(0.008)	(0.016)	(0.008)	(0.007)	
PRACTICES	0.006	0.010**	0.007*	0.003	1.75
	(0.004)	(0.005)	(0.004)	(0.004)	

***Significant at 1% level; **significant at 5% level; *significant at 10% level. Standard errors are shown in parenthesis. M.E.

6.9 Conclusions

The objective of this chapter was to estimate and compare efficiency scores and determinants from different approaches namely parametric stochastic input distance function (SIDF), non-parametric input distance functions(VRS DEA and CRS DEA) and parametric stochastic frontier production function (SFPF). In all the models, it was found that maize farmers in Benue State have considerable technical, allocative and cost inefficiency dominated by the later suggesting the immense potential of enhancing production through improvement in overall efficiency. Two approaches were employed in the analysis of technology and farm characteristics impact on efficiency namely t-test of equality in means and second stage Tobit regression. In general, the results from the two approaches suggest that technological innovations and other policy variables had positive and significant impact on technical, allocative and cost efficiency in most cases. The positive and significant impact of the included technological innovation variables shows the role of government technology policy in enhancing farm efficiency in Nigeria and therefore underscores the need for further investment into agricultural research and technology development. Strengthening the hybrid seed sectors was found to be especially very important and the results were robust in both t-test and Tobit analysis and in all the models.

In addition to the comparison of absolute values of efficiency scores from the four models, formal sensitivity tests were conducted. The overall consistency check shows that technical, allocative and cost efficiency measures from the three distance functions (SIDF, VRS DEA and CRS DEA) were consistent whereas similar conclusions could not hold when these were compared to the production frontier (SFPF) especially for technical efficiency estimates. Given the consistency of results from the parametric and non-parametric distance functions, an integrated model is therefore proposed and this is addressed in the next chapter.