Technical Efficiency of Coal Mines: A Stochastic Frontier and Data Envelopment Analysis for Eastern Salt Range of Punjab

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Abstract

This paper investigates the technical efficiency of the 29 coal mines in the eastern salt range of Punjab using parametric as well as non-parametric frontier techniques. The results show that there has been some improvement in the efficiency of the coal mines, though the magnitude of improvement remains small. By using SFA All coefficients are statistically significant except that of salaries, wood packing cost and fuel and electricity, which is insignificant. A possible explanation may be that the presence of rigidities in terms of salaried workers lay off may prevent firms from an optimal utilization of the employee input secondly wood packing chargers increased due to different mine areas because this expanse depends on the area. Similarly, due to load shedding in Pakistan cause the inefficiency in fuel and electricity cost. The results from both the approaches are consistent, and in line with similar studies. The results also shows a mixed technical efficiency scores for the coal mines. However the coal seam, age of mine manager, experience of mine manager, and qualification of mine manager have directly proportional impact on the technical efficiency of the mines. Whereas vertical depth of coal mine and length of coal mine has adverse impact on the efficiency of the coal mine.

Key Words: Coal Mines; Technical Efficiency; SFA; Punjab

Introduction

Coal mining is one of the most hazarders; difficult and dangerous mining where in coal is exploited and used for the heat generation on the domestic, local and industrial. Pakistan is ranked 7th internationally regarding lignite coal reserves but unluckily Pakistan steel has imported 2.84 mt to 4.27 mt coal per year between 2006 to 2011. It is just because we are still unable to explore our resources of coal. The coal mining in Pakistan still conducted on artisanal method which has less production and efficiency. Punjab has large reserves of coal but the deposits need to be exploited for provincial and national development. In Punjab coal reserves are present in the salt range. The salt range is a hill system deriving its name from its extensive deposits of rock salts. The range extends from Jehlum river to the Indus across the northern portion of the Punjab province. The salt range coal field covers an area of 13000 sq km. The range contains the great reserves of coal. The coal is mainly present in Eastern salt range, Central salt range and Trans Indus areas. In these areas estimated 0.235 billion tons coal is present. There are more than 500 coal mines in this range and average reported annual output production is 10 million tons approximately. The thickness of the coal seam varies from 0.3 to 2.0 meters with an average of 0.43 meters. The quality of coal ranges from lignite to sub bituminous. There are more then 150 productive mines in the eastern salt range. The vertical depth of coal mines in the eastern range is almost same which is between 250 feet to 300 feet and coal seam is an average 2.1 feet. However, rocks are different similarly water level is also different in different areas. In Pakistan coal mining is still artisanal. Which is also the cause of less coal production. However, in develop countries now mechanized

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mining is started. There is not exists substantial literature on efficiency assessment of coal mines. Due to which coal mines unable to improve their efficiency.

There might be several reasons for relatively low interest in the issue in developing countries like Pakistan. First, efficiency assessment of inputs is an often seen as an issue related to the degree of mechanization and engineering mining. However, mining in developing countries is still to large extent artisanal and there has been little productivity improvement. Secondly, to undertake valid analysis researchers need good data which is often not available in Pakistan. Data is the main problem for analysis because even the mine owners do not co-operates which creates real problem for researchers. Third no government agency collects exact data mines related to cost and coal output.

This study aims to assess the technical efficiency of the coal mines in eastern salt range of Punjab using two competing techniques i.e. the stochastic frontier analysis (SFA) and data envelopment analysis (DEA). The theoretical literature on technical efficiency can be traced back to Debreu (1951), Koopmans (1951), and Shephard (1953). Farrell (1957) introduced the concepts of cost efficiency and allocative efficiency, devised a method to decompose cost efficiency into allocative and technical components, and applied linear programming techniques to empirically measure technical efficiency. The underlying idea in Farrell's work is an efficient frontier against which the performance of productive units can be measured. Following these early works, many writers tried different techniques to estimate/compute the production frontier and efficiencies. Two such techniques which have drawn wide attention from empirical researchers are (i) Stochastic Frontier Analysis (SFA), and (ii) Data Envelopment Analysis (DEA).

Literature Review

Benchmarking can be helpful in suggesting the efficiently use of inputs by way of overall cost reduction and cycle time which improves the Productivity of Coal mines. Reddy *et al.* (2013) tried to measure the efficiency of the coal mines. Research used Data envelopment Analysis (DEA) using variables, wage cost, store cost, OBR Cost and other costs as inputs and Production as output. Research used data from 15 open cast mines. Research concluded that After Benchmarking it is found that there is sufficient scope for improvement in coal mines.

Traditional DEA models ignore the internal process of production system and are not able to identify the cause of deficiency in efficiency measuring. K. Shahroudi et al (2011).

Sengupta () estimated the efficiency of the coal mining industry. Research employed Data Envelopment Analysis (DEA) and used variables such as Labor, Fuel and Capacity. Research finds out we can measure the efficiency by combining cost efficiency with flexibility in flexible manufacturing systems, allocative efficiency for determining the optimal levels of inputs and finally, filtering methods applied to stochastic input output data sets.

Lei and Ri-jia (2007) estimated the efficiency of Safety inputs using Data Evelopment Analysis (DEA). Research used data from coal mine in china for the time span of 2001 to 2005. Research analyzed variables like as Costs of different safety measures. The safety input resources can be optimized and adjusted, analysis shows that, on average in 2001 and 2004, 45% of the expended funds could have been saved. Likewise, 10% of the safety management and technical staff could have been eliminated and working hours devoted to safety could have been reduced by 12%. These conditions could have given the same results.

The efficiency evaluation has been done by using the tool of Data Envelopment Analysis (DEA). DEA is a Mathematical tool/technique for evaluating the operational efficiency of systems that exhibit homogeneous characteristics having inputs and outputs. Sofianopoulou (2006) has used DEA for the evaluation of a vast variety of systems ranging from the retail services and education to industrial production.

Coelli (2008) developed a computer program Data Envelopment Analysis (DEA) for calculating efficiency of the firms using inputs and outputs.

Methodology

This study utilises two competing techniques i.e. the SFA and DEA to estimate a production frontier which will serve as a benchmark to estimate the technical efficiencies of various industries. Whereas the SFA is based on parametric estimation, the DEA uses non-parametric linear programming technique. These competing techniques are based upon different sets of assumptions: SFA requires specific functional form and allows for random noise; the DEA does not require a specific functional form but ignores the random noise. Some studies, for example Banker, Gahd and Gorr (1993), report from a Monte Carlo experiment that the relative precision of DEA and SFA may be context specific. DEA might be the preferable technique where assumptions of typical neoclassical production theory are in question and measurement errors are unlikely. On the other hand, SFA has the advantage in handling measurement errors but functional form should closely match the properties of the underlying production technology. With this perspective it seems plausible that the analysis should be based upon alternative techniques to ensure robust conclusions.

Our approach is output-oriented, i.e. we seek to maximize output for a given level of inputs. The study covers 29 mines for the years 2012-13.

The Stochastic Production Frontier is assumed to be of Cobb-Douglas form with a composite error term:

$$\boldsymbol{lnY = \beta^{o} + \beta_1 lnW_i + \beta_2 lnS_i + \beta_3 lnWp_i + \beta_4 lnM_i + \beta_5 lnF_i + \beta_6 lnR_i + \beta_7 lnMic_i + V_i - U_i}$$

$$i = 1 \dots \dots \dots n$$

Y_i *is output of* i *mines*
W_i *is wages of* i *mines*
S_i *is salaries of* i *mines*
Wp_i *is wood packing cost of* i *mines*
M_i *is mine maintaince cost of* i *mines*
F_i *is fuel and electricity cost of* i *mines*
R_i *is Repair and maintaince cost of machaniry of* i *mines*
Mic_i *is Miscelenous cost of* i *mines*
V_i is a component of the error term with normal distribution
U_i is a component of error term with half-normal distribution

Data and Summary Statistics

Cross sectional data collected in face-to-face interviews are used in this study. A pretested questionnaire was administered to collect information from the mine owners in the eastern salt range of Punjab. The questionnaire contains information on the personal characteristics of the miners, education of mine manager, area of mine, vertical depth of mine, coal seam, mining experience, length of the mine, total output of coal per year, and cost of operations of the mine. List of the mines operating in the district chakwal were obtained from the office of the Directorate of Mineral Development Chakwal Punjab. A total of 29 mines were included following a random sampling procedure. The survey was conducted during December 2013 and January 2014.

For the empirical application we worked with data on a survey of 29 underground mines. For our analysis we have chosen seven input variables namely, wages cost (in million Rs), Salaries cost (in million Rs.) , Wood packing cost (in million Rs.) , Maintaince cost of mines

(in million Rs.) , Fuel cost (in million Rs.) Repair cost of machinery (in million Rs.) , Miscellaneous cost (in million Rs.) and one output variable namely coal production (in millions Rs.)

Table 1: Input and Output variables used in the analysis

Input/ Output	Variables	Underground mine cost
Input-1	Wages cost	It includes all the wages paid to employees including coal cutter
Input-2	Salaries cost	It includes all the salaries paid to employees
Input-3	Wood packing cost	It includes all the wood cost used in the mine
Input-4	Mines maintaince cost	It includes all the cost of the maintaince of the mine
Input-5	Fuel and electricity cost	Cost of POL, electricity and any fuel cost on mine
Input-6	Repair cost of machinery	Total repair cost of machinery, change of machinery
Input-7	Miscellaneous cost	Any other cost incurred in the mine
Output	Production (output)	Saleable coal

Environmental variables

Sr. No	Variable
1	**Vertical depth of coal mine**
2	**Length of coal mine**
3	**Seam of coal**
4	**Age of mine manager**
5	**Qualification of mine manager**
6	**Experience of mine manager**

Result and Discussion

The Stochastic Frontier Technique

The model is estimated by maximum likelihood method the results are reported in Tables 1. All coefficients are statistically significant except that of salaries, wood packing cost and fuel and electricity, which is insignificant. A possible explanation may be that the presence of rigidities in terms of salaried workers lay off may prevent firms from an optimal utilization of the employee input secondly wood packing chargers increased due to mine areas because this expanse depends on the areas similarly due to load shedding in Pakistan cause the inefficiency in fuel and electricity cost. The magnitude of the parameter gamma is 0.000089 an indication that inefficiencies are not the major component of the composite error terms.

Table No.2

variables	Coefficients	Standard error	T ratios
Constant	4.7698	1.431	3.3321
Wages	0.2899	0.1022	2.8349
Salaries	0.7677	0.1156	0.6636
Wood Packing	0.0812	0.0935	0.8687
Mine maintenance cost	0.1017	0.0943	1.9793
Fuel and electricity	0.1055	0.0824	1.2796

Repair and maintains of machinery	0.1985	0.0931	2.1326
Miscellaneous	0.0134	0.0034	3.861
Sigma squared	0.1090	0.0285	3.8217
Gamma	0.0001	0.0273	0.0032
likelihood ratio test of one-sided error=9.01			

The likelihood ratio test of one-sided error gives a value of 9.01 for the given year, implying that the use of stochastic frontier is justified. Overall, the mean efficiency score is 0.9993, indicating the overall efficiency of the mines. This increase in technical efficiency may be due to improving competition and creating a better business climate for domestic and foreign investors. The reforms resulted in an increased role of market forces in resource allocation and this in turn helped improve the efficiency of most of the mines.

Table 3. Technical efficiency estimates

Stochastic frontier		Data Envelopment Analysis	
Firm	**Technical efficiency**	**Crs Te**	**Vrs Te**
1	0.9992133	1.000	1.000
2	0.99921540	1.000	1.000
3	0.99921401	0.544	0.720
4	0.99921250	0.440	0.447
5	0.99921490	0.995	1.000
6	0.99921432	1.000	1.000
7	0.99921472	0.507	1.000
8	0.99921498	0.703	1.000
9	0.99921564	1.000	1.000
10	0.99921456	0.817	0.856
11	0.99921392	0.546	0.695
12	0.99921398	0.516	0.859
13	0.99921356	0.610	0.668
14	0.99921355	0.610	0.649
15	0.99921661	1.000	1.000
16	0.99921477	0.600	1.000
17	0.99921453	0.598	0.887
18	0.99921447	0.671	0.672
19	0.99921523	0.776	0.849

20	0.99921420	0.539	0.540
21	0.99921604	1.000	1.000
22	0.99921773	1.000	1.000
23	0.99921566	1.000	1.000
24	0.99921432	1.000	1.000
25	0.99921450	1.000	1.000
26	0.99921450	1.000	1.000
27	0.99921669	1.000	1.000
28	0.99921437	0.744	0.912
29	0.99921473	1.000	1.000
Mean Efficiency	0.99921475	**0.801**	**0.888**

Data Envelopment Analysis

In terms of the DEA, the efficiency scores have been computed under the assumptions of constant as well as variables returns to scale. With constant returns to scale, the mean efficiency score improved from 0.801. At the disaggregated level, results are largely similar to those derived under stochastic frontier.

Constant Return to Scale Technical Efficiency:

It is efficiency measured against the Constant Return to scale frontier. The technical efficiencies of the respective mines for the period of one years are in the Table.

Table 4. EFFICIENCY SUMMARY			
Mines	**Crste**	**Mines**	**Crste**
1	1.000	**16**	0.600
2	1.000	**17**	0.598
3	0.544	**18**	0.671
4	0.440	**19**	0.776
5	0.995	**20**	0.539
6	1.000	**21**	1.000
7	0.507	**22**	1.000
8	0.703	**23**	1.000
9	1.000	**24**	1.000
10	0.817	**25**	1.000
11	0.546	**26**	1.000
12	0.516	**27**	1.000
13	0.610	**28**	0.744
14	0.610	**29**	1.000
15	1.000		
Mean	**0.801**		

The above Table is depicting the Technical efficiencies of the mines. Among the performance of the mines in cross sectional data, Mine no 1,2,6,9,15,21,22,23,24,25,26,27 and 29 are found to be the most technically efficient across the whole time period. The minimum efficiency score of some mines is only around 44% during this period. The average efficiency score for the mines in this time period of analysis is found to be around 80.1%, which is showing that there low inefficiency in the mines in Eastern salt range.

Variable Return to Scale Technical Efficiency:

It is efficiency measured against the Variable Return to scale frontier. The technical efficiencies of the respective mines for the period of one years are in the Table.

firm	Vrs Te	Firm	VrsTe
1	1.000	16	1.000
2	1.000	17	0.887
3	0.720	18	0.672
4	0.447	19	0.849
5	1.000	20	0.540
6	1.000	21	1.000
7	1.000	22	1.000
8	1.000	23	1.000
9	1.000	24	1.000
10	0.856	25	1.000
11	0.695	26	1.000
12	0.859	27	1.000
13	0.668	28	0.912
14	0.649	29	1.000
15	1.000		
Mean		**0.888**	

The above Table is depicting the Technical efficiencies of the mines. Among the performance of the mines in cross sectional data, Mine no 1,2,5,6,7,8,9,15,16,21,22,23,24,25,26,27 and 29 are found to be the most technically efficient across the whole time period. The minimum efficiency score of some mines is only around 44.7% during this period. The average efficiency score for the mines in this time period of analysis is found to be around 88.8%, which is showing that there low inefficiency in the mines.

Scale Efficiency:

Scale efficiency measures can be obtained for each mine by conducting both a CRS and a VRS DEA, and then decomposing the TE scores obtained from the CRS DEA into two components, one due to scale inefficiency and one due to pure technical inefficiency. If there is a difference in the CRS and VRS TE scores for a particular mine then this indicates that firm has scale inefficiency.

Firm	Scale	Return to scale	firm	Scale	Return to scale
1	1.000	-	16	0.600	DRS
2	1.000	-	17	0.674	DRS
3	0.756	DRS	18	0.999	IRS
4	0.984	IRS	19	0.914	DRS
5	0.995	DRS	20	0.998	IRS
6	1.000	-	21	1.000	-
7	0.507	DRS	22	1.000	-
8	0.703	DRS	23	1.000	-
9	1.000	-	24	1.000	-
10	0.955	DRS	25	1.000	-
11	0.811	DRS	26	1.000	-
12	0.600	DRS	27	1.000	-
13	0.914	DRS	28	0.816	DRS
14	0.939	DRS	29	1.000	-
15	1.000	-			
Mean			**0.902**		

The above Table is depicting the Scale efficiencies of the mines. Among the performance of the mines in cross sectional data, Mine no 1,2,6,9,15,21,22,23,24,25,26,27 and 29 are found to be the most scale efficient across the whole time period. The average efficiency score for the mines in this time period of analysis is found to be around 90.2%. However, there are 16 mines among 29 mines which are scale inefficient and these mines are mine no 4, 5, 7, 8, 10, 11, 12, 13, 14, 16, 17, 18, 19, 20, and 28. In these mines mostly mines have decreasing return to scale. Which shows that increase in inputs are more than increase in output. So by increasing the inputs of these mines the output will not increase with that rate.

Conclusion

This paper has examined the efficiency of the mines in the eastern salt range of punjab using two competing techniques, i.e., the Stochastic Frontier Analysis, and the Data Envelopment Analysis. The results on the basis of stochastic production frontier show that the mine sector has efficient. These findings are broadly supported by the Data Envelopment Analysis. However, there is still significant room for improvement in the efficiency levels of some mines. A comparison of efficiency scores across techniques shows that on average, and in most of the cases efficiency scores using the stochastic frontier are higher than those obtained by using the data envelopment analysis. Within the data envelopment analysis, the efficiency scores are higher in case of variable returns to scale than those under the assumption of constant returns to scale. This is in line with the evidence suggested in the literature. By using SFA all coefficients are statistically significant except that of salaries, wood packing cost and fuel and electricity, which is insignificant. A possible explanation may be that the presence of rigidities in terms of salaried workers lay off may prevent firms from an optimal utilization of the employee input secondly wood packing chargers increased due to different mine areas because this expanse depends on the area. Similarly due to load shedding in Pakistan cause the inefficiency in fuel and electricity cost.

The DEA analysis shows that all inefficiency factors included in the model are significant and determine the sources of inefficiency. The two stage DEA analysis shows that only thirteen mines could gain technical efficiency. Al though, there is a significant growth in technical but still the DMUs are producing below the frontier. It indicates that there is capacity to improve the performance of the sector. Regarding of age of mine manager, qualification of mine manager, experience of mine manager and seam of coal mine, has the directly proportional impact on the technical efficiency of the coal mines.

The efficiency of the mines can improve by taking some measures, i-e improve mine ventilation, man riding and hauling system

Finally, the analysis also shows seam of the coal mine is the major factor which has direct impact on the efficiency. If the coal seam is large and continued then mine can easily able to reach at technical efficient score.

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