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ARTICLE INFO	Oludele Akinloye, Akinboade, Emilie Chanceline Kinfack, Mandisa Putuma, Mokwena and Wolassa L. Kumo (2010). Estimating profit efficiency in the South African mining sector using stochastic frontier approach. *Problems and Perspectives in Management*, *8*(1-1)
RELEASED ON	Thursday, 01 April 2010
JOURNAL	"Problems and Perspectives in Management"
FOUNDER	LLC “Consulting Publishing Company “Business Perspectives”

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Estimating profit efficiency in the South African mining sector using stochastic frontier approach

Abstract

This paper analyzes profit efficiency of selected mining firms in South Africa over the 2003-2006 period. A stochastic frontier analysis method was used. The estimated model shows the presence of stochastic frontier profit possibilities. All variables that affect profitability of the firm are highly significant. The fourteen firms covered are ranked in terms of their efficiency performance over this period. At 37%, the average profit efficiency of 50% of firms or 7 firms is above the overall average.

Keywords: profit efficiency, mining sector, stochastic frontier analysis.
JEL Classification: C51, L25, L72, M21.

Introduction

The South African economy is currently characterized by high level of unemployment, abject poverty, low productivity and low international competitiveness whereas small and medium enterprises in South Africa constituted 55 percent of all jobs and 22 percent of gross domestic product (GDP) in the year 2003 (*S*aravanan et al., 2008). Some researchers advocate promotion and support of these firms on the basis of both economic and welfare arguments (You, 1995). It is argued, for instance, that an expansion of the small-firm segment leads to more efficient resource allocation, less unequal income distribution and less under-employment because small firms tend to use more labor intensive technologies. Furthermore, a large number of small firms may constitute a seedbed for young entrepreneurs. In addition to these arguments, technical efficiency of small firms may be higher as a result of their being exposed to more competition than larger firms.

Only few studies have been conducted to analyze profit efficiency in South Africa. One example is South Africa Revenue Service (2008), Akinboade et al. (2008) and Akinboade et al. (2009). This is somewhat surprising given the importance of measuring the profit efficiency of an industry and the significant role that small and medium enterprises play in economic growth. Thus, it is important to not only focus on how government must improve the business environment, studies also have to shed light on how to improve the productivity of firms in South Africa. The problem of measuring the profit efficiency of an industry is hence important to both the economic theorist and the policy maker. If government policy is to improve industrial performance, it will be important to know how far a given industry can be expected to increase its profit by simply increasing its efficiency, without absorbing further resources.

Hence, the main objective of this paper is to undertake an assessment of the profit efficiency of selected firms in the mining sector of South Africa over the 2003-2006 period. The rest of the paper is structured as follows: a brief discussion of why it is important to improve profit efficiency in the mining sector is presented in the first section, followed by a discussion of profit efficiency measurement. Later, we outline data sources and model specification before presenting the empirical application and results. The last section concludes the paper.

1. Why it is important to improve profit efficiency in the mining business

The traditional relationship between mining and the environment was previously based on a negative perception of involvement in environmental pollution. However, in 1995 the World Business Council for Sustainable Development (WBCSD) was established with a view towards promoting business' understanding of sustainable development. In their understanding of sustainable development the WBCSD has recognized the responsibility of business to both grow their economic impact whilst simultaneously acting in a manner that is acceptable to society.

South Africa is one of the world's and Africa's most important mining countries in terms of the variety and quantity of minerals produced. It has the world's largest reserves of chrome, gold, vanadium, manganese and PGMs. South Africa is the leading producer for nearly all of Africa's metals and minerals production.

It is estimated that South Africa holds 80% of the world's known manganese reserves as well as 72% of the world's known chromite ore reserves. In 2005, South Africa was found to be the ninth-largest producer of aluminium, the largest producer of alumino-silicates, chrome ore and ferro-chromium. South Africa was also found to be the second-largest producer of manganese ore and the ninth-largest producer of nickel in the same year.

The economic benefits of mining are also reflected in the contribution to direct foreign exchange earnings of the country. In the 1970s and 1980s, gold exports were the predominant source of foreign exchange earnings, with mining contributing around 14% of total value added in the economy. In 2007, mining and quarrying contributed about 5.8% to the country's gross domestic product (GDP).

However, mining as an industry is crucial to South Africa's economic growth, with precious metals contributing 65% to the country's mineral export earnings and 21% of total exports of goods in 2006. The country supplies about 80% of the world's platinum.

The mining industry is also South Africa's biggest employer, with around 460 000 employees and another 400 000 employed by the suppliers of goods and services to the industry.

The gold industry remains the largest employer, responsible for more than 50% of total employment, estimated at 420 000 people in 2000. Mining also accounts for more than 40 percent of the market capitalization of the JSE Securities Exchange South Africa.

Also, developments in the mining sector directly affect Millenium Development Goals (MDGs), especially poverty and undernourishment. Mining is a major private-sector supplier of social infrastructure including schools, clinics and other essential facilities in parts of the country where poverty is endemic.

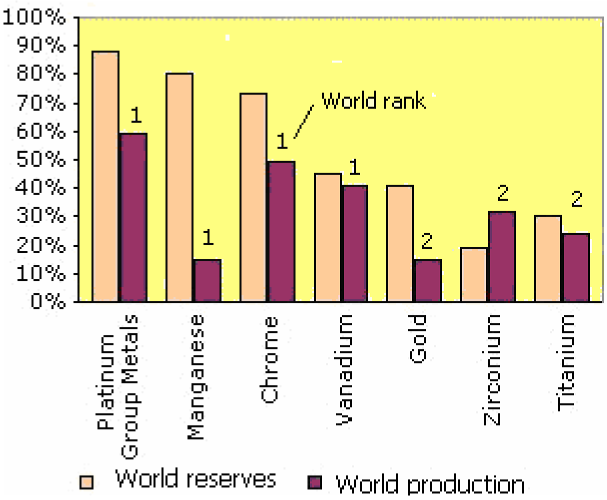

Fig. 1. South Africa's ranking in global minerals production

2. The profit efficiency model

The profit efficiency model derives inspiration from the project based approach to audit selection in Australia. It focuses on taxable income of taxpaying entities. A detailed discussion of the profit efficiency model is contained in Syed and Kalirajan (2000). The definition of profit efficiency is in relation to the economic objective of profit maximization.

Two profit functions are distinguished in the literature, depending on whether or not there is market power: the *standard* profit function and the *alternative* profit function. The standard profit function assumes that markets for outputs and inputs are perfectly competitive. Given the input and output price vectors, the individual retail firm maximizes profits by adjusting the amounts of inputs and outputs. In the alternative profit function, firms take as given the quantity of output and the price of inputs. They maximize profits by adjusting the price of the output and the quantity of inputs. Efficiency ranges over the (0,1) interval.

Profit efficiency of an individual firm, PE_i is defined as the ratio of the observed profit (Q) to the corresponding frontier profit (Q^*).

$$PE_i = Q/Q^* \quad (1)$$

Profit efficiency is measured through benchmarking profitability from a group of firms within a particular industry. Let N be the number of firms. Suppose the i^{th} firm has a vector of X independent inputs that determine profit. Then, the stochastic profit function is defined as:

$$InQ_{it} = \beta InX_{it} + (V_{it} - U_{it}),$$
$$i=1\text{------}N \quad (2)$$
$$t=1\text{-----}\ T$$

where InQ_{it} = the log of profit of the i^{th} firm in time period t. InX_{it} = $a\ K\ x\ l$ vector of logs of revenue and cost of the firm in the time period t. β = a vector of unknown parameters. V_{it} = random variables which are assumed to be $_{iid}$ $N(0, \sigma^2/v)$. $U_{it} \Rightarrow$ non-negative random variables which are assumed to account for profit inefficiency and are assumed to be $_{idd}$ as truncations at zero of the $N(\mu, \sigma^2/\mu)$.

The maximum likelihood (MLE) method is employed to obtain the estimates of the coefficients (β) of the stochastic profit frontier function and the predicted profit efficiency. The variance parameters are expressed in terms of:

$\sigma^2 = (\sigma^2_u + \sigma^2_v)$ and

$\gamma = (\sigma^2_u / \sigma^2_u + \sigma^2_v)$.

When the i^{th} firm effectively employs the best practice governance method to obtain maximum possible profit, then μ_i will take a value of zero. However, this maximum profit could vary among firms which are using different levels of inputs based on their fixed endowments. If any firm were to adopt the best governance practice, it would generate Q_j^*, such that $Q_j^* = Q_j$.

High and significant values of Q_i indicate the presence of stochastic profit possibilities and that the variation in profit performances among firms is not just due to factors beyond the control of firms, but also due to firm specific governance factors influencing profit efficiency. When it is assumed that the impact emanating from a firm's poor governance is effective, then the firm will show slackness in effectively using inputs to obtain their maximum possible profit. The i^{th} firm's profit function can hence be written as follows:

$$f(Qi) = \frac{1 - F(-\mu^*/\sigma^*)}{(2\pi)\frac{1}{2}\left(\sigma_u^2 + \sigma_v^2\right)\frac{1}{2}\left[1 - F(-\mu/\sigma_u)\right]} \exp^{-\frac{1}{2}\left[\left(\frac{(u_i - v_i)}{\sigma_v}\right)^2 + \left(\frac{\mu}{\sigma_u}\right)^2 - \left(\frac{\mu^*}{\sigma^*}\right)^2\right]} \quad (3)$$

Thus, the profit efficiency of the i^{th} firm, which distils stochasticity in the profit frontier from firm specific efficiency is given by:

$$PE_i = exp\ (-\mu_i) = Q/Q^*. \quad (4)$$

3. Estimating profit performance benchmarks

Any analysis of the behavior of a firm or industry requires clear recognition of the character of its output and of the input of the resources employed, and any empirical analysis of efficiency requires that these quantities should be measurable (Hall and Knapp, 1955).

Theoretically, the profits of any specific mining firm may deviate from that of the best practice mining firm due to two main factors: uncontrollable random shocks and controllable mine specific profit inefficiencies. Uncontrollable random shocks include external shocks such as amendments in mining sector legislation or unanticipated changes in demand for mining products. The controllable profit inefficiencies can be attributed to internal mine specific governance factors including, for example, underreporting of income or inflation of certain cost items.

Another important issue is what determines the performance of a mining firm. This study uses profits as a measure of performance. Variability in profitability is related to income and expenditure in the production operations of a mining entity and benchmarked for it.

Benchmarking is a process (1) for identifying the best performers, and thereby the gap between these best performers and others, and then (2) for explaining the reasons for the gap with an eye to taking corrective action to close the gap. Traditionally, it has often been carried out for the general information of company managers or analysts.

Stochastic Frontier Analysis and Data Envelopment Analysis are the most common approaches for benchmarking and efficiency studies. The two methods are examples of, respectively, parametric and non-parametric techniques.

Data Envelopment Analysis (DEA) is a non-parametric approach that determines a piecewise linear efficiency frontier along which the most efficient firm derives relative efficiency measures of all other firms in the sample. It is simple and it yields useful interpretation results even when data are limiting. It is widely used in the operations research and management science literature. Instead of estimating the impact of different cost drivers, DEA establishes an efficiency frontier (taking account of all relevant variables) based on the "envelope" of observations. Each firm is then assigned an efficiency score based on its proximity to the estimated efficiency frontier (NERA, 2006). The efficiency of a particular company is then measured by its distance from the estimated frontier.

One criticism of DEA is often related to its sensitivity to outliers. The technique often finds companies to be efficient purely as a result of their being an outlier rather than because their costs are low (NERA, 2006). The technique tends to characterize many companies as being on the efficient frontier, particularly when there are several cost drivers in the model.

Parametric techniques (such as stochastic frontier analysis (SFA), Corrected Ordinary Least Squares (COLS) and some others) are based on regression analysis. They specify a particular form of relationship between a firm's costs or production and a set of cost drivers, which might include, for example, the outputs produced, input prices and a range of exogenous factors. These models make use of some econometric techniques to estimate the parameters of that relationship.

The Stochastic Frontier Method (Aigner et al., 1977a, b) then sets benchmark standards, both here and in general, since the method provides an estimate of relative-performance-based standards that can control both for: (i) relative levels of potential excess expenditures to produce given levels of outputs, and (ii) random exogenous factors affecting levels of expenditures.

Stochastic frontier analysis (SFA) is the econometric methodology that should be used to simultaneously benchmark best performance and to explain the benchmark gap between current performance and best performance. This approach is not so influenced by outliers though it requires the shape of the frontier to be known, or assumed, in advance.

In this study, our objective in estimating benchmarks for mining firms is to identify a profit frontier which reflects the minimum total expenditures needed to achieve specified levels of outputs.

4. Data and model used in the study

Panel data from 14 small to medium size mining firms in South Africa have been used in this study. Relevant data on small and medium sized firms in the sector of South Africa are difficult to access. Therefore, selected firms were those for which relevant data are available in public domain. These data set, covering 2003 and 2006 (the most recent that are available) from company income statements, includes information on variables that affect corporate profitability for these firms. These are taxable income, sales revenue, wage bill, gross interest, other income, total expenses, interest expenses, current assets.

Following Syed and Kalirajan (2000), we specify a log-linear functional model of the stochastic frontier profit function as follows.

$$InQ_{it} = \beta_0 + \beta_i InX_{it} + (v\text{-}\mu \text{ for } i=1\text{-}8 \text{ and } t=1\text{-}4, \quad (5)$$

where the variables are as described in Table 1.

V_{it} are as defined earlier and U_{it} ~N (m_{it}, s_u^2), where m_{it} = Z_{it}d, Z_{it} is the vector of firm-specific variables which may influence the firms' efficiency. The estimation of the above equation will yield the potential profit (taxable income) Q^*_i for individual firms. Given our log-linear specification, adjustments had to be made for the few firms experiencing negative profits. We hence follow closely the suggestions of Fitzpatrick and McQuinn (2005) and adjust the profit levels in the sample such that the profit level for the firm with the largest negative amount corresponds to log(0+1) = 0.

4.1. Empirical model specification of profit efficiency. In common with the literature, the package used in the study and estimated by maximum likelihood is FRONTIER 4.1 (Coelli, 1994).

Herrero and Pascoe (2002) review the technical characteristics of FRONTIER 4.1 software and others. FRONTIER 4.1 was created specifically for the estimation of production frontiers. It is a relatively easy tool to use in estimating stochastic frontier models, it is flexible in the way that it can be used to estimate both production and cost functions, it can estimate both time-varying and invariant efficiencies, or when panel data are available, and it can be used when the functional forms have the dependent variable both in logged or in original units.

FRONTIER solves two general models. The error components model can be formulated as

$$Y_{it} = X_{it}\,\beta + (V_{it} - U_{it}), \quad (6)$$

where Y_{it} is the (logged) output obtained by the i-th firm in the t-th time period; X_{it} is a (kx1) vector of (transformation of the) input quantities of the i-th firm in the t-th time period; β is a (kx1) vector of unknown parameters; and V_{it} are assumed to be iid N(0, σ_v^2) random errors, and $U_{it} = U_i \exp(-\eta(t-T))$, where U_i are assumed to be iid as truncations at zero of the N(m_i, σ_u^2).

FRONTIER 4.1 incorporates maximum likelihood (ML) estimation of parameters. The estimation process consists of three main steps. First, OLS is applied to estimate the production function. This provides unbiased estimators for the β's (except for the intercept term and the variance estimate). The OLS estimates are then used as starting values to estimate the final ML model. The value of the likelihood function is estimated for different values of γ between 0 and 1 given the values for the β's derived in the OLS. Finally, an iterative Davidon-Fletcher-Powell algorithm calculates the final parameter estimates, using the values of the β's from the OLS and the value of γ from the intermediate step as starting values.

If $\eta>0$, the inefficiency term, U_{it}, is always decreasing with time, whereas $\eta<0$ implies that U_{it} is always increasing with time. That could be one of the main problems when using this model, technical efficiency is forced to be a monotonous function of time.

The second model included in the FRONTIER package is the Technical Efficiency (TE) effects model (Battese and Coelli, 1995). According to Herrero and Pascoe (2002), there are two approaches to estimating inefficiency models. It could be done in either a one step or a two step process. If the two-step procedure is used, the production frontier is first estimated and the technical efficiency of each firm is derived. These are subsequently regressed against a set of variables, Z_{it}, which are hypothesized to influence the firms' efficiency. A problem with the two-stage procedure is the inconsistency in the assumptions about the distribution of the inefficiencies. In the first stage, the inefficiencies are assumed to be independently and identically distributed (iid) in order to estimate their values. However, in the second stage, the estimated inefficiencies are assumed to be a function of a number of firm specific factors, and hence are not identically distributed unless all the coefficients of the factors are simultaneously equal to zero (Coellli, Rao and Battese, 1998). FRONTIER uses the ideas of Kumbhakar, Gosh and McGuckin (1991) and Reifschneider and Stevenson (1991). It estimates all of the parameters in one step to overcome this inconsistency. The inefficiency effects are defined as a function of the firm specific factors (as in the two-stage approach) but they are then incorporated directly into the Maximum Likelihood Estimate (MLE).

5. Results

5.1. Maximum likelihood estimates of frontier production function in the mining sector. The maximum likelihood estimates of the stochastic frontier profit function of the selected mining firms in South Africa are reported in Table 1. A significant positive (negative) coefficient for any variable suggests that it increases (decreases) the firm's profit efficiency.

The estimated model shows the presence of stochastic frontier profit possibilities. The value of Gamma (γ) is close to 1 and significant at 1%. The likelihood ratio is significant at 5%. This suggests that the overall model estimated is significant.

All explanatory variables that affect profitability of the mining firm analyzed are highly significant. The total wage bill, interest expenses and other expenses all have significant negative effects on the profit efficiency of the mining firms. Their coefficients are significant at 1%. Similarly, Sales revenue, Gross interest income, other income and Asset size all have significant positive effects on the profitability of the mining sector firms. The coefficients of these variables are all significant at 1% level except that of the Gross interest income which is significant at 5%. However, the time trend variable in the Efficiency component model is not significant.

Table 1. The maximum likelihood estimates of the stochastic profit frontier for selected firms in the mining sector

Dependent variable: taxable income ***Number of observations: 56*** ***Period: 2003-2006***			
Explanatory variables	Coefficient	Standard error	t- values
Constant (β_0)	-12.28	0.273	-45.03***
Total wage bill	-0.014	0.003	-4.14***
Sales revenue	0.758	0.009	82.09***
Gross interest income	0.038	0.016	2.3**
Interest expenses	-0.312	0.0015	-211.8***
Other income	0.227	0.0013	171.16***
Asset size	1.76	0.031	56.71***
Other expenses	-1.13	0.094	-12.03***
Constant (δ_0)	-4.19	1.73	-2.42**
Z (trend)	-0.383	0.353	-1.08
Variance statistics			
Sigma squared	68.67		
Gamma (γ)	0.999		

Notes: Log Likelihood function = -151.11. Likelihood ratio test = 41.04**. *** indicates significance at 1%. ** indicates significance at least at 5%.

5.2. Profit efficiency of selected firms in mining sector. It is important for the profit performance of mining firms to be benchmarked against each other in the sector. Profit performance also needs to be ranked over this period. This could assist the industry to develop strategies to improve performance and decrease inefficiencies. The distribution of profit efficiencies for mining firms for this period is presented in Table 2.

Table 2. Profit efficiency of selected firms in mining sector, 2003-2006

Firm	Name of the firm	2003	2004	2005	2006	Average	Rank
1	Denver Quarries Pty Ltd	0.670	0.831	0.989	0.405	0.724	1
2	Poggenpoel Diamond Cutting Works CC	0.291	0.494	0.680	0.997	0.616	4
3	Supermix Mining Pty Ltd	0.000005	0.0000007	0.0000002	0.00000005	0.000001	14
4	Stone and Allied Industries (OFS) Ltd	0.00001	0.000005	0.000004	0.000001	0.000005	13
5	De Aar Stone Crushers	0.682	0.289	0.623	0.998	0.648	2
6	Metal Concentrators Pty Ltd	0.114	0.330	0.644	0.328	0.354	7
7	SPH Kundalila Pty Ltd	0.00005	0.00006	0.00002	0.997	0.249	9
8	Ernest Blom Diamonds CC	0.000001	0.00001	0.0022	0.0259	0.007	12
9	ADR Mining & Plant Supplies CC	0.349	0.999	0.515	0.502	0.591	5
10	Lidonga Minerals Pty Ltd	0.970	0.0006	0.001	0.0003	0.243	10
11	Rietspruit Crushers Pty Ltd	0.249	0.280	0.076	0.365	0.243	10
12	Prominence Mining Services CC	0.989	0.837	0.478	0.179	0.621	3
13	MB Metals Pty Ltd	0.994	0.295	0.632	0.217	0.535	6
14	White River Crushers CC	0.107	0.0929	0.182	0.995	0.344	8

The average profit efficiency for all 14 firms analyzed is 37%. The deviation between the lowest and the highest average profit efficiency is very high. The lowest average profit efficiency is 0.0001% while the highest average profit efficiency is 72.4%. Average profit efficiency of 11 firms is above 20%.

The average profit efficiency of 50% of firms or 7 firms is above the overall average. These firms are: 1, 2, 5, 6, 9, 12 and 13. The average profit efficiency of 50% of the firms or 7 firms is below the overall average. These firms are: 3, 4, 7, 8, 10, 11, and 14. Firms 3, 4 and 8 are consistently performing low in terms of profit efficiency.

5.3. Tracking the efficiency ranking over time. Another issue of relevance to the study is the tracking of mining firm's efficiency over time. Given that we had access to firm level data on the 14 firms over 4 years, such an analysis has been undertaken.

There are two ways of performing SFA on mining data collected over time. First, four separate SFAs can be run for each time period. In such an analysis, the efficiency of any mining firm may not be directly compared with efficiency of another firm in different time periods, including itself. The efficiencies are relative and are computed by looking at performance data of firms included in that analysis (or time period) only. Hence, for example, it may not be valid to compare the efficiency of firm number 1 in 2003 with its efficiency in 2006 or the efficiency of firm number 2 in 2006. However, the comparison of rank orders of firms from different time periods may be meaningful. Hence, we can compare the rank of firm number 1 in 2003 with its rank in 2006 or the rank of firm number 14 in 2003 with its corresponding ranking in 2006.

Table 3 presents the ranking of mining firms by tracking their efficiency ranking over time.

Due to the fact that retail data for 14 firms for 4 years were pooled to create 56 observations (14 x 4 time periods) and used in our analysis, it is therefore possible to compare firm-level efficiency and track it over time. Hence, now we can compare the efficiency of, say firm number 1 in 2003 with its efficiency in 2006 and the efficiency of firm number 2 in 2006.

The yearly rankings of most of the firms are reasonably close. From Table 3 we can see that firm numbers 3, 4, and 8 have been consistently ranked between 11 and 14. Compared with others these mining firms are the poor performers. Firm number 10 consistently deteriorated in ranking over this period. Firm number 2 improved from 8th position in 2003 to second in 2005 and 2006. Similarly, firm number 14 improved in efficiency ranking from 10th in 2003 to 4th in 2006.

Table 3. Tracking profit efficiency ranking of selected firms in mining sector, 2003-2006

Firm	Name of the firm	2003	2004	2005	2006	Average rank
1	Denver Quarries Pty Ltd	5	3	1	6	1
2	Poggenpoel Diamond Cutting Works CC	8	4	2	2	4
3	Supermix Mining Pty Ltd	13	12	13	14	14
4	Stone and Allied Industries (OFS) Ltd	12	14	12	13	13
5	De Aar Stone Crushers	4	7	5	1	2
6	Metal Concentrators Pty Ltd	9	5	3	8	7
7	SPH Kundalila Pty Ltd	14	13	14	3	9
8	Ernest Blom Diamonds CC	11	11	11	11	12
9	ADR Mining & Plant Supplies CC	6	1	6	5	5
10	Lidonga Minerals Pty Ltd	3	10	10	12	10
11	Rietspruit Crushers Pty Ltd	7	8	9	7	10
12	Prominence Mining Services CC	2	2	7	10	3
13	MB Metals Pty Ltd	1	6	4	9	6
14	White River Crushers CC	10	9	8	4	8

Conclusion

Our paper applied stochastic frontier analysis to estimate the profit efficiency of selected mining sector firms in South Africa. The estimated model shows the presence of stochastic frontier profit possibilities. All variables that affect profitability of the firm are highly significant. Mining firms in our sample have been ranked according to their profit efficiency performance. With few exceptions, yearly profit efficiency performances in the mining sector vary. Only a small number of firms perform above the average efficiency of 50%.

In the mining sector, the average profit efficiency for all 14 firms analyzed is 37%. The average profit efficiency of 50% of firms or 7 firms is above the overall average. These firms are: 1, 2, 5, 6, 9, 12 and 13. The average profit efficiency of 50% of the firms or 7 firms is below the overall average. These firms are: 3,4,7,8, 10, 11, and 14.

Profit efficiency ranking of firm numbers 3, 4, and 8 have been consistently low. Firms numbers 2 and 14 improved profit efficiency performance ranking over this period.

Profit efficiency benchmarking technique could potentially be used to identify financial statement fraud – that is the net income is overstated, rather than understated. This could very much assist policy makers in the internal revenue departments.

However, efficiency analysis reflects relative advantage and identifies those mining firms which seem to be more successful in obtaining lower costs or higher profits. It does not identify why, exactly, they are more successful. Indeed, relative success is attributed to excluded influences in a cost or profit function that are hard to measure − such as internal productivity, the effects of firm policies and procedures, and regional or country business environments − so that firms further away from the frontier are deemed to be more "inefficient".

Some two limitations of efficiency analysis are noted in the literature. First, it is suggested that if certain internal firm productivity and external business environment influences are added to either standard profit or cost function stochastic or linear programming frontier models, average firm efficiency can rise to over 95%. In that case measured inefficiency could be greatly reduced[1]. Second, once differences in input prices, funding mix, output levels, productivity indicators, and service delivery levels have been included in the analysis, they are not (by definition) a source of cost or profit inefficiency even though these differences may be important sources of observed cost/profit differences[2].

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[1] See Carbó, S., Humphrey, D., and López, R. (2007).
[2] See Humphrey (2008).