

## Technical Efficiency Measurement and Occupational Safety Level. The Case of Greek Lignite Mining

I.E.Tsolas

*Department of Geotechnology and Environmental Engineering, Technological Educational Institution of Western Macedonia, Greece*

**ABSTRACT:** The purpose of this paper is to measure technical efficiency in Greek lignite mining using not only conventional input-output data, but also mine accident data over the period 1970-96. Technical efficiency is measured using the basic Data Envelopment Analysis (DEA) model, which takes into account conventional data (i.e., real output, labor and fixed capital) and the number of disabling injuries. The latter are treated as input and alternatively as a joint 'negative' output in alternative applications of the basic DEA model. In the light of the combined results, the treatment of disabling injuries as either input or output provides fairly similar results (i.e., for one and a half decades, the Hgnite production system at the sectoral level operated efficiently, reaching the maximum potential output level only over the period 1989-91 and in 1996).

### 1 INTRODUCTION

#### 1.1 *Technical efficiency measurement - Data Envelopment Analysis*

Work that has been done on measuring efficiency can be categorized into techniques that use a parametric or stochastic frontier production approach and those that use a non-parametric or linear programming approach (Forsund et al., 1980). Data Envelopment Analysis (DEA) is a modern technique of operations research which is used for efficiency measurement and belongs to the non-parametric approach.

The measuring of efficiency using a non-parametric approach began essentially with the pioneering work of Farrell (1957). Then, Chames et al. (1978) revived Farrell's efficiency measure as a technique and coined the term DEA. The new technique was based on a linear programming problem for measuring the efficiency of decision management units (DMUs). DMUs are different production units which operate under similar conditions, employing the same inputs and producing the same outputs.

Most studies so far have used cross-section data evaluating the performance of various production units, but it should be noted that Burley (1980) used the technique for measuring efficiency at the sectoral level. DEA was applied in the mining industry by Byrnes et al. (1984) to a sample of Illinois strip mines.

The present paper uses time series of data for measuring the technical efficiency in Greek lignite mining over a long period. The term technical or productive efficiency is used mainly by economists in order to describe how well an organizational unit is performing in utilizing resources to generate outputs or outcomes. In our case, DEA sheds light on the composition of productivity differential among compared yearly activities, using not only conventional input-output data (Burley, 1980; Tsolas, 1995a; Tsolas, 1995b; Tsolas & Panagopoulos, 1996), but also aggregate mine accident data over the period 1970-96. Technical efficiency is measured using a DEA model which takes into account, in addition to real output (i.e., excavated lignite) and labor and capital inputs (i.e., man-shift hours paid and fixed capital respectively), the number of disabling injuries. The latter are treated as input and alternatively as a joint 'negative' output in different input-output DEA models. The treatment of mine accident data is similar to that of the environmental data in DEA applications (Tsolas, 1996).

DEA is based on mathematical programming principles and provides the technical efficiency scores of each one of the yearly activities over the period 1970-96. Activities are deemed efficient only if technical efficiency scores are equal to unity; the difference between unity and technical efficiency score yields the percentage of potential output loss due to inefficiency.

## 1.2 Occupational safety

Unlike technical efficiency, safety does not readily lend itself to definition in a quantitative manner; rather it is a qualitative, judgmental factor related to the acceptability of risks (Zabetakis, 1981).

Various studies on productivity and safety (Zabetakis, 1981; Tsolas & Panagopoulos, 1995) are based on the assumption that there is *a priori* a negative correlation between productivity and safety, and present some empirical evidence at the sectoral and mine level respectively through the derivation of regression models. According to the results of a recent study (Tsolas & Petrakis, 2000), the above assumption seems to be unrealistic in the case of Greek lignite mining as far as the disabling injuries are concerned. In the light of these results, disabling injuries are treated as input and alternatively as a joint 'negative' output in different input-output DEA models.

The study aims to present some evidence regarding productive efficiency in Greek lignite mining in relation to occupational safety level. For this, an extended input-output data set is used in which, apart from real output, labor and capital, disabling accidents are also included.

## 2 METHODOLOGICAL FRAMEWORK

### 2.1 Occupational safety as a joint 'negative' output

Work-related accidents are considered as a joint 'negative' output of the production process. Given a set of  $n$  inputs, say  $X = (X_1, X_2, \dots, X_n)$ , firms are considered to be able to produce along a product transformation frontier marketable output ( $Q$ ) and accident output ( $A$ ) combinations. Using a dual-output production frontier of the form  $F(Q, A, X) = 0$ , a product transformation curve, like the one in Figure 1, in which input levels are assumed to be constant, summarizes the transformation possibilities of the firms; in other words, the trade-off between occupational safety and marketable output. Movements along this curve are achieved by reallocating inputs from output-producing to accident-reducing activity. The slope of this curve is positive because:

$$dQ/dA = -(\partial Q/\partial X)/(\partial A/\partial X) \quad (1)$$

where  $dQ/dA > 0$  because the production of marketable output  $Q$  requires input  $X$  and  $\partial A/\partial X < 0$  because the reduction of accidents requires input  $X$ .

This curve defines a positive opportunity cost for reducing accidents.

The discussion above is based on the assumption that firms can alter the incidence of accidents and hi-

framed with a technological trade-off between safety and marketable output. If changes in accidents are instead random, then it would be expected that a negative relationship between accidents and output would be observed. In this case, a reduction of accidents would be beneficial for the firm in terms of fewer disruptions to production, and thus increased productivity.

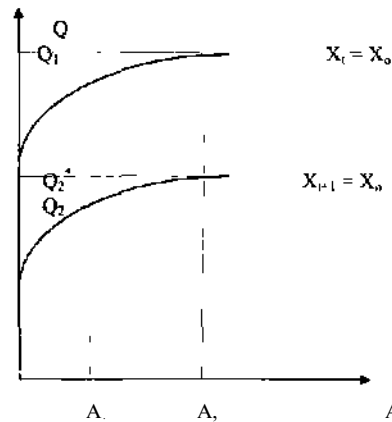


Figure 1 Product transformation frontier, see also Sider (1983)

### 2.2 Technical efficiency measurement using DEA

Technical efficiency is obtained from the solution of the following problem, which is known as the basic DEA model (Charnes et al., 1978):

Given a set of  $n$  yearly activities (YA)  $Y_{Aj}$  ( $j=1,2,\dots,n$ ), each with a set of  $m$  inputs  $x_{ij}$  ( $i=1,2,\dots,m$ ) and a set of  $M$  outputs  $y_{kj}$  ( $k=1,2,\dots,M$ ), determine for one particular YA, say  $Y_{Ap}$ , with inputs  $x_{ip}$  and outputs  $y_{kp}$ , whether it is efficient; in other words, whether  $w$  equals one, which stems from the following linear programming problem under the assumption of constant returns to scale:

$MUX \ V$  subjretto

$$\sum_{j=1}^n x_{ij} \lambda_j \leq x_{ip}, \quad i=1,\dots,m$$

$$\sum_{j=1}^n y_{kj} \lambda_j \leq y_{kp} w, \quad k=1,\dots,M$$

$$w, \lambda_j \geq 0$$

Activities are deemed efficient (i.e., DEA scores = 1.00) if they are not dominated by any other pure activity or a.i.y of their subset

### 3 DATA SET

Real output, labor input, capital input and occupational mine data are considered here. The data are drawn from the National Statistical Service of Greece and the Ministry for Development, Directorate of Policy for Mineral Resources (see also Tsolas & Petrakis, 2000).

#### 3.1 *Real output*

Real output is measured in terms of excavated lignite tonnage. An unadjusted measure of physical output is more accurate for a homogenous product (Darmstadter, 1997). In the case of Greek lignite, a decrease in the heating content of excavated lignite implies a downward adjustment in the level and rate of change in productivity and vice versa, but limitation of the data restricts the analysis to that direction.

#### 3.2 *Labor input*

Labor input is measured in terms of aggregate (white and blue collar) total man-shift hours paid (including those for illnesses, accidents and days off).

#### 3.3 *Capital input*

In order to keep track of changes in capital equipment, a perpetual inventory method is used. Thus, whenever there is a new investment in equipment, it is added to the capital stock and remains there until it is declared 'retired' from assets. The average useful service life is taken to be equal to 20 years and is used as the basis for this 'retirement'.

Capital input is the physical use of machinery and equipment, with depreciation taken as an approximation of the capital consumed in the production process.

The model applied here for the estimation of fixed capital is a 'service flow model' because physical inputs are converted into drachmas that are payments for services provided by capital inputs. For the conversion in constant 1970 drachmas, a deflator constructed by the Ministry of National Economy's services (Ministry of National Economy, 1998) was used (Tsolas, 2000). This model views productivity as the measure of the efficiency of the conversion process (Green & Green, 1985; Tsolas & Petrakis, 2000).

#### 3.4 *Occupational mine data*

The occupational mine data include disabling injuries over the period 1970-96.

### 4 INPUT-OUTPUT MODEL FORMULATION

Following the analysis presented above, three input-output (I/O) models and respectively three DEA models are considered.

i) Model 1 uses excavated lignite as output, and man-shift hours paid, fixed capital and disabling injuries *as inputs*.

ii) Model 2 uses excavated lignite and disabling injuries as outputs, and man-shift hours paid and fixed capital as inputs.

iii) Model 3 uses excavated lignite as output, and man-shift hours paid and fixed capital as inputs.

The occupational mine data are incorporated into model 1 as input under the assumption that they represent the inflated monetary values of an extra cost and alternatively, into model 2 as "negative" output (reciprocal values are entered into the model).

In the first model, they are treated as an extra cost which reflects the cost of improving working conditions, workforce hygiene, etc. The application of DEA therefore uses the disabling injuries as input and discriminates the activities using lower cost to produce a particular yearly output level.

In the second model, they are treated as a 'negative' output; according to DEA, the more the outputs (more lignite produced and less injuries occurred), the better the efficiency.

In the third model, only conventional input-output data are used.

### 5 RESULTS

The estimated technical efficiency scores for each one of the input-output models are presented in Table 1. Spearman rank order correlation coefficients are presented in Table 2.

On the whole, the DEA scores show among others that the yearly activities over the period 1989-91 and in the year 1996 had relatively high efficiency. Therefore, the performance of the sector at the end of the 90s and in the final year of the period studied can be considered satisfactory.

Both input-output models 1 and 3 give fairly similar results. This is due to the fact that there is a positive correlation between disabling injuries and production (Tsolas & Petrakis, 2000), and as a result, the agreement between the rankings in models 1 (conventional data) and 3 (conventional and occupational data) is very satisfactory.

Model 2, in which occupational data are treated as negative output, was used as an alternative to model 1. A comparison of these results with those of model 3 shows that the treatment of disabling injuries as a negative output provides similar results.

For a discussion of the results, the risk level of Greek lignite mining and its effect on total factor productivity (TFP) measurement should be taken into account.

Table 1. PEA scores.

	Model 1	Model 2	Model 3
1970	86.90	100.00	82.51
1971	100.00	100.00	100.00
1972	99.82	97.75	95.49
1973	94.25	93.97	90.06
1974	83.73	85.03	83.73
1975	94.15	95.90	93.90
1976	100.00	100.00	100.00
1977	100.00	100.00	97.80
1978	88.66	88.59	82.19
1979	85.31	85.89	80.05
1980	74.90	74.82	70.41
1981	78.17	76.37	73.76
1982	69.28	69.57	67.27
1983	69.43	95.63	68.52
1984	72.46	100.00	72.44
1985	76.25	89.64	76.23
1986	80.10	96.71	79.62
1987	80.09	91.10	79.90
1988	95.30	95.30	95.30
1989	100.00	100.00	99.60
1990	100.00	100.00	100.00
1991	100.00	100.00	100.00
1992	89.32	88.59	88.56
1993	86.19	86.19	86.19
1994	90.18	90.18	90.18
1995	97.98	97.98	97.98
1996	100.00	100.00	100.00

Table 2. Spearman rank order correlation coefficients.

	Model 1	Model 2	Model 3
Model 1	-	0.682*	0.980*
Model 2	-	-	0.673*

Source: Table 1.

\* Correlation is significant at the level of .01 (2-tailed).

As far as the incidence rate (i.e., injuries per 200,000 man-hours) is concerned, there was a notable decline during the 70s, but since 1981 this decline has not accelerated further. Moreover, it seems that the risk levels associated with disabling injuries have not changed markedly; this was especially true during the 80s (Tsolas & Petrakis, 2000).

Moreover, a comparison of productivity growth, as it is measured either using conventional inputs and output (Tsolas, 2000) or accounting for changes in the working environment, shows a similar trend

for most years of the time period studied (Tsolas & Petrakis, 2000).

The points above reinforce the combined results of this paper; all three models provide fairly similar results. It should be noted that the model which treats occupational safety data as output (model 2) provides better DEA scores for 1983-87 than the other models, though both models which use occupational safety data (models 1 and 2) provide better DEA scores especially during the second half of the 70s as compared with the model which uses conventional data (model 3). This is probably due to the continuous decline in the incidence rate over the 70s.

## 6 CONCLUSIONS

In the present paper, disabling injuries are considered as an input and alternatively as a joint 'negative' output for the lignite production system in order to measure the technical efficiency of the whole system over the period 1970-96. The technical efficiency is measured through the application of the classical DEA model.

From the combined results of various input-output models considered here, the agreement between the rankings could be deemed satisfactory, especially in the case where occupational data are treated as input. This is reinforced by the fact that comparison of the productivity growth, as it is measured either using conventional inputs and output or accounting for changes in the working environment, shows a similar trend for most years of the time period studied (Tsolas & Petrakis, 2000).

Although the incorporation of disabling injuries into the input-output models provides similar results, there is slight evidence that treating occupational data as "negative" output improves the discriminative power of the basic DEA model applied here.

However, it is worth noting that the present paper has some limitations that could be explored by future research, such as the scale efficiency (Byrnes et al., 1984). It is considered that, if more detailed and comprehensive data (e.g., waste volume processed, another 'negative' output imposed by geological factors, intermediary inputs, etc.) are made available and the assumption of constant returns to scale is relaxed, the results of newly formulated DEA models will be more reliable.

## REFERENCES

- Burley, H. 1980. Productive efficiency in US manufacturing: A linear programming approach. *Review of Economics and Statistics* 619-622.
- Byrnes, P., Fare, R., & Grosskopf, S. 1984. Measuring productive efficiency: an application to Illinois strip mines. *Management science* 30,6:671-681.

- Chames, A. , Cooper, W. W. & Rhodes, E. 1978. Measuring the efficiency of decision making units. *European Journal of Operational Research*. 2:429-444.
- Darmastadter, J. (with the assistance of Kropp, B.). 1997. *Productivity change in US coal mining*. RFF Discussion Paper 97-40, Resources for the Future.
- Green, A. G. & Green, M. A. 1985. *Productivity and labor costs in the Ontario Metal Mining Industry*, Mineral Policy Background, Paper no 19,3271, Canada.
- Farrell, M. J. 1957. The measurement of productive efficiency *Journal of the Royal Statistical Society*. Series A, 120:253-281.
- Førsund, F.'C, Lovell, A. K & Schmidt, P. 1980. A survey of frontier production functions and their relationship to efficiency measurement, *Journal of Econometrics*. 13: 5-26.
- Ministry for Development, Directorate of policy for the mineral resources. 1975-1996. Official data for man-shift hours in mining activities, unpubl. (in Greek).
- Ministry of Industry, General Directorate of Mines. Various years, 1970-1974. *Bulletin on the mining activities of Greece* (in Greek).
- Ministry of National Economy, General Directorate for Economic Policy, Directorate for Macroeconomic Analysis. 1998. *77th Greek economy 1960-1997. Statistical long-term macroeconomic series* (in Greek).
- National Statistical Service of Greece. Various years, 1970-1996. *Annual statistical survey on mines, quarries and salt-works* (in Greek).
- Sider, H. 1983. Safety and productivity in underground coal mining. *77th Review of Economics and Statistics*. 65, 1: 225-233
- Tsolas, I. E. 1995a. *Analysis of labor productivity in the Greek mining industry*, Ph.D. thesis, Athens, National Technical University, Department of Mining and Metallurgical Engineering (in Greek).
- Tsolas, I. E. 1996. Environmental effects on the efficiency of thermal electrical power production sector. In E. Diamantopoulos & G. Korfiatis (eds). *Protection and Restoration of the Environment III, Proc. intern. symp., Chania, 28-30 August 1996: 444-451* Chania' Technical University of Crete.
- Tsolas, I. E. 1995b. Productive efficiency in Greek lignite mining, an application of the DEA model. In B. Papathanassiou and K. Papamzoz (eds), *3rd Balkan Conference on Operational Research, Proceedings, Vol. II, Proc. symp., Thessaloniki, 16-19 October 1995:1239-1252*. Thessaloniki: Hellenic Operational Research Society.
- Tsolas I. E. & Panagopoulos C. I. 1996. Measurement of technical efficiency at the mine level - The cases of Kardia-Field and South-Field strip lignite mines of Ptolemais - Amydaio Lignite Center in western Macedonia, *Mineral Wealth* 100: 23-36 (in Greek).
- Tsolas, I. E. & Panagopoulos, C. I. 1995. Study of labor productivity at the mine level - The cases of Kardia-Field and South-Field strip lignite mines of Ptolemais-Amydaio Lignite Center in western Macedonia *Mineral Wealth* 95: 39-54 (in Greek).
- Tsolas, I. E. 2000. Productivity measurement at the sectoral level The case of Greek lignite mining. In Panagiotou, G. N. and Michalakopoulos, T. N. (eds.), *Mine planning and equipment selection, Proc intern symp., Athens, Nov. 6-9, 2000: pp491-496*, Balkema, Rotterdam.
- Tsolas I. E. & Petrakis, A. 2000. Productivity and occupational safety in the Greek lignite mining. In *29th International Symposium on Computer Applications in the Mineral Industries, APCOM. Proc. intern symp., Beijing, 25-27 April 2001. forthcoming*
- Zabetakis, M.G 1981. Productivity and safety in US bituminous coal mines. *Mining Congress Journal*. 19-21.

