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Project Title: **EFFICIENCY AND PRODUCTIVITY ANALYSIS OF ILLINOIS COAL MINES**

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ABSTRACT

Using the stochastic production frontier model, the technical/productive efficiency of twelve underground coal mines in Illinois has been estimated for the period 1989 to 2003. The loss in output due to inefficiency for each year for each mine has also been estimated and some factors contributing to inefficiencies at these mines have been identified. Next, the output growth is decomposed into three components: growth due to change in technical efficiency, growth due to technological progress, and growth due to change in inputs. Finally, output elasticities of capital and labor were determined to shed some light on economies of scale at these mines, i.e. the role capital and labor have played in production.

The overall average technical/productive efficiency of all twelve mines considered in this study from 1989 to 2003 is 69%. The total output produced by these mines during the period of study was 376.6 million tons. However, our estimation results reveal that, due to inefficiency, these mines lost 171.8 million tons of coal production during the 15-year period. Thus, the maximum possible output that could have been produced by these mines during the same period was 548.5 million tons.

Besides the amount of labor and capital used, factors that contributed to increased efficiency were seam thickness and prep plant capacity. However, other factors such as depth of coal seam, injury frequency rate, and age of mine have contributed to inefficiency. The output growth of these twelve mines was negative between 1991/1992; 1996/1997; 2000/2001; 2001/2002 and 2002/2003 and positive the remainder of the time. Negative growth periods were due to negative growth in inputs and negative changes in technical efficiencies. Our results reveal that the rate of technological progress has been decreasing throughout the period of study. In other words, the rate of improvements in technology has been slowing down.

Finally, we note that the elasticity of output with respect to capital is negative. Basically, this implies that an increase in capital would not increase output if the labor, in terms of man hours worked, remained the same. However, the output elasticity of labor is positive and has been increasing from 1989 to 2003. The average elasticity of labor for these twelve mines is 0.975, meaning that if labor (in terms of man hours) is increased 10%, output will increase 9.75% by using the same amount of capital.

EXECUTIVE SUMMARY

Economists and industrialists have long been concerned with measuring the performance of firms that convert inputs into outputs. Inputs could be capital, labor, energy, materials and technology among others. Basically, when economists talk about efficiency they are trying to answer the following questions. First, are producers using capital, labor and other inputs efficiently in their production process? In other words, can they produce more output with the same amount of input? Second, to produce the same amount of output, can they reduce the amount of inputs? This type of efficiency is called technical or productive efficiency. This efficiency is measured by comparing a firm to other producers in the same industry or to its own past. The other type of efficiency that economists have been interested in estimating is cost efficiency. Here the concern is whether firms are producing output with minimum cost. The questions to be asked are, first, can a firm reduce the cost of producing the same amount of output? Second, how cost efficient is a particular firm as compared to other producers in the same industry or as compared to its own past? In some industries, such as banking, it is more relevant to estimate profit efficiency.

The latest methodology to estimate productive cost or profit efficiencies is to use stochastic production cost or profit frontier models. The production frontier represents the maximum output attainable from each input level. The word “frontier” emphasizes the idea of maximality and represents the “best practice” approach to production. Hence, it reflects the current state of technology in the industry. Firms in the industry operate either on the frontier if they are technically/productively efficient or beneath the frontier if they are not technically efficient. Thus, a producer (in this case, a coal mine) is technically efficient if, and only if, it is impossible to increase output without increasing any input. An individual mine’s interest will be what their productivity measure is in terms of output growth as compared to other mines within the industry or how has output growth increased or decreased at that mine over the years. The other thing of interest to mine management would be to identify factors which have affected output growth.

When comparing productivity through time, an additional source of productivity change, called technological progress or technical change, is possible. This involves advances in technology, which may be represented by an upward shift in the production frontier. With change in technology, in time period two all firms can technically produce more output for each level of input, relative to what was possible in time period one. By using the stochastic frontier methodology, the output growth of each mine is decomposed into three components: output growth due to growth in inputs, output growth due to change in technical efficiency, and output growth due to technological progress. Thus, when it is observed that a mine has increased its productivity from one year to the next, the improvement may not have been from efficiency improvements or the exploitation of economies of scale (i.e. changes in input) alone, but may have been due to technological progress. It is also possible that productivity improvements result from a combination of all three factors.

There were several objectives of this study. The first was to collect all of the available data from existing underground coal mines in Illinois on output produced (i.e. clean coal) and inputs used (i.e. capital and labor) during production over an extended period of time. The second objective was to use a stochastic production frontier model to estimate the technical/productive efficiency of all the mines. A frontier production function defines the maximum output achievable under current technology with available productive factors. Third, the loss in production due to technical inefficiency was estimated. Fourth, some of the determinants of inefficiency were identified. The fifth objective was to decompose output growth into three components: growth due to technological progress, growth due to change in technical efficiency and output growth due to input growth. Sixth, the determinants of output growth were analyzed. Seventh, output elasticities of capital and of labor were estimated to shed some light on the economies of scale of these mines. Finally, some observations are made as to how the findings of this study can be used by the coal industry.

To achieve the above objectives, relevant data was collected from all of the underground coal mines in Illinois. The availability of data became a critical issue in the study. In the end, only twelve mines were included since they were the only mines for which consistent data could be acquired for a long enough time-span. The output considered is the clean coal measured in annual tons each mine operation shipped to its customers. The horsepower of the mining machines employed in the harvesting of coal from the underground face is used as a measure of capital due to lack of availability of capital data in terms of dollar values of equipment, building etc. Horsepower is the second best measure of capital but it is often used in the absence of actual dollar values. The labor is measured in terms of total man hours worked per year in the mine.

To investigate the factors contributing to technical efficiency, the following variables were considered: seam thickness or the height of the coal seam measured in feet; depth to the coal seam from the surface measured in feet; Injury Frequency Rate (IFR) or a measure of the number of reportable lost time accidents as related to total hours worked at the mine; Injury Severity Rate (ISR) or a measure of the number of hours lost per injury; administration to total labor ratio (A/L ratio) or the ratio of administrative personnel hours to total labor hours; age of the mine in terms of the number of years the mine has been in operation; and preparation plant capacity or the coal cleaning capacity in tons per hour. This data was collected for the time period from 1989 to 2003.

The main findings of this study can be summarized as follows. The overall average technical efficiency of all twelve mines considered in this study during the 1989 to 2003 period is 69%. This means that these mines produced 69% of the potential output they could have produced by using the same resources in the most efficient manner. The total clean coal produced by these mines during the period of study was 376.6 million tons. This study reveals that due to inefficiency these mines lost 171.8 million tons of coal production. In other words, they could have produced up to 548.4 million tons. There is a clear distinction among mines. Three mines are around 80% technically efficient, four mines are in the 69% to 76% efficiency range, and the other five mines are in the 50% to 65% range. It was observed that the amount of output produced per man hour and the amount of output produced per unit of horsepower played a clear role in contributing to the technical efficiency or inefficiency of these mines. Besides the amount of labor and capital used, other factors which contributed to inefficiency were the coal seam depth from the surface, injury frequency rate and age of the mine. On the other hand, coal seam thickness and prep plant capacity contributed towards an increase in efficiency.

From 1989 to 2003, output growth from one year to the next for the twelve mines studied was negative five times (from 1991 to 1992, from 1996 to 1997, from 2000 to 2001, from 2001 to 2002 and from 2002 to 2003) and positive nine times. The negative growth periods were due to negative growth in inputs and negative changes in technical efficiencies. Furthermore, technical efficiency change has been negative in eleven out of fourteen years and input growth has been negative seven times out of fourteen years. For the twelve mines in the study, the rate of technological progress has been decreasing over the entire time period. In other words, the rate of improvement in technology has been slowly diminishing. This falling trend in technological progress indicates that there are limits to the use and access of newer and more advanced technology in the mining industry.

Analyzing the output growth of individual mines, we note that during the study period, three of the twelve mines had negative output growth. At eight mines, we observed negative change in technical efficiencies and at seven mines we noted negative input growth. Thus, at seven of the twelve mines, output growth is affected by negative input growth and/or negative efficiency growth. Finally, we noted that the average elasticity of output with respect to capital is negative. The negative elasticity of capital implies that an increase in capital would not increase output if the amount of man hours worked remains same. In fact, output may decrease even with an increase in capital. On the other hand, the output elasticity of labor is positive and has been increasing from 1989 to 2003. The average elasticity of labor is 0.975. In other words, if man hours are increased by 10%, the output will go up by 9.75%.

To summarize the study results, it can be inferred that there is room for some underground coal mines in Illinois to improve their productivity by increasing their productive efficiency. In addition to improving efficiency, there is room for productivity improvement by increasing the number of man hours used in production while maintaining the same amount of capital. However, any increase in capital needs to be complimented with an increase in man hours to increase output growth.

Finally, we offer a word of caution. The findings of any study are as good as the data used. As with most empirical studies, there are some shortcomings in this study too. We would have preferred to use the capital input in terms of dollar value of equipment, building, etc., which accounts for new and old machines. Also, the data for some mines at a few time points was missing and had to be interpolated.

OBJECTIVES

The overall goal of this study was to estimate technical/productive efficiency and analyze the productivity of Illinois coal mines by using a stochastic production frontier model over a specified time span depending on the availability of the data. To accomplish this overall objective, the study was organized into a set of specific tasks, as outlined below.

- First, compile a comprehensive data set for the mining industry that consists of output, inputs, and other variables suspected of being the determinants of inefficiency for each mine operating over the last 10-15 years. Output is measured in tons of clean coal shipped by each operation. Labor input is measured in man-hours employed at the mine. Capital is measured in terms of dollar values of machines, equipment, buildings, etc. used each year by the mines. Since this type of data is often not available in any public data source, a questionnaire for obtaining such information was prepared and sent to all mines. All public data sources pertaining to the mining industry are to be considered.

- Second, perform preliminary data analysis to expose any outliers or other anomalies that may be present.

- Third, estimate technical/productive efficiency for each year and for each mine in the study using a stochastic production frontier model.

- Fourth, identify the determinants of inefficiency. Here the variables considered are: age of mine, depth to seam, seam thickness, prep plant capacity, and injury frequency rate.

- Fifth, quantify the significance of inefficiency by analyzing the loss in output due to inefficiency for each operation and for the industry as a whole.

- Sixth, decompose output growth into three components: growth due to technological progress, growth due to change in technical efficiency, and output growth due to input growth. This step included analyzing the determinants of output growth.

- Seventh, estimate the output elasticity of capital and labor for each mine and the industry as a whole and analyze the roles of capital and labor in the production process.

- Finally, make some observations as to how the findings of this study could be used by the industry.

INTRODUCTION AND BACKGROUND

When economists discuss efficiency they are concerned with investigating a basic question concerning efficient use of inputs in the production process. Can firms produce more output with the same amount of inputs or can they reduce the amount of inputs and achieve the same output level? This type of efficiency is referred to as technical or productive efficiency. An enormous amount of empirical evidence across all kinds of manufacturing industries, farms, banks, etc. suggest that not all producers succeed in utilizing the minimum inputs required to produce the output they choose to produce, given the technology at their disposal. These firms are described as being technically inefficient.

Koopmans (1951) defines technical/productive efficiency as a feasible input output vector where it is technically impossible to increase any output (or reduce any input) without simultaneously reducing another output (or increasing another input). Additionally, Farrell (1957) proposed that technical/productive efficiency has two components. The purely technical or physical component refers to the ability to avoid waste through output augmentation with a given set of inputs and/or input conservation for a given amount of output. The other component is allocative efficiency, which refers to the ability to combine inputs and outputs in optimal proportions at their prevalent prices, under a behavioral assumption for the decision-making unit, e.g. cost minimization, revenue maximization.

Note that a production frontier describes the technical relationship between the input and output of a production process. It defines the maximum outputs attainable from a given set of inputs. The word “frontier” emphasizes the idea of maximality and represents the “best practice” approach to production. Hence, it reflects the current state of technology in the industry. Firms (or, mines in our case) in that industry operate either on the frontier if they are technically efficient or beneath the frontier if they are technically inefficient.

Consider the case of a firm that produces an output Y using one input X according to the production function Y= f(X). Figure 1 is a graphical representation of the production function. Line OF is the production frontier that defines the relationship between input and output. It is the maximum output attainable for each level of input; hence it reflects the current state of technology in the industry. Firms in the industry operate on the frontier if they are technically/productive efficient or beneath the frontier if they are technically inefficient. Point A represents an inefficient point whereas B and C represent efficient points. A firm operating at point A is inefficient because technically it could increase its output to the level associated with point B without employing additional input. Alternatively, it could produce at point C on the frontier and attain the same level of output while using less input. Thus, a producer is technically efficient if, and only if, it is impossible to produce more of any output (in the case of multiple outputs) without producing less of some other output or using more of some input. For practical purposes, interest naturally centers on the magnitude of inefficiency and on the determinants of inefficiency.

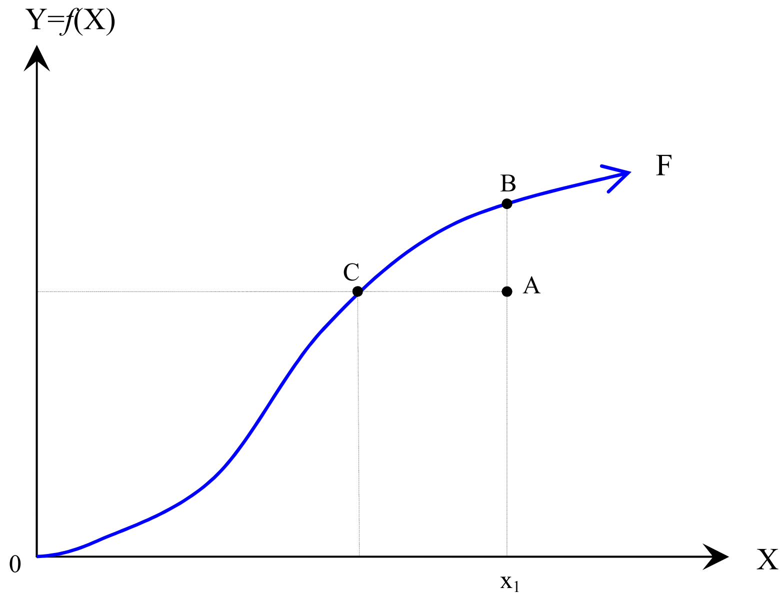


Figure 1. Graphical Representation of the Production Frontier

From figure 1, Technical Efficiency (TE) = OA/OB = (Observed Output)/(Maximum Possible Output). Thus, the maximum possible output, OB = (Observed Output)/(TE).

Knowing whether producers are efficient or inefficient gives rise to other questions. For example, how is their productivity measure, i.e. output growth as compared to other firms within the industry? Or, for an individual mine, has the output growth increased or decreased over the years? The other thing of interest to mine management would be to identify the factors which have affected output growth. When we compare productivity through time, an additional source of productivity change, called technological progress or technical change, is possible. This involves advances in technology which may be represented by an upward shift in the production frontier. With changes in technology, in time period two, all firms can technically produce more output for each level of input, relative to what was possible in time period one.

By using the stochastic frontier methodology, the output growth of each mine is decomposed into three components: output growth due to growth in inputs, output growth due change in technical efficiency, and output growth due to technological progress. Thus, when we observe that a mine has increased its productivity from one year to the next, the improvement need not have been from efficiency improvements alone, but may have been due to technological change, or due to the exploitation of economies of scale (i.e. due to change in inputs) or, from a combination of all three factors.

EXPERIMENTAL PROCEDURES

A. Stochastic Frontier Analysis

A frontier production function defines the maximum output achievable under the current technology with available factors of production. Productivity variations at mines can arise due to different factors, most notably, economies of scale, technology, and other exogenous sources, as well as differences in efficiency. Instead of using cross sectional data, researchers prefer to employ panel data because panel data has more information than does a simple cross section. Another advantage of using panel data is that efficiency can also be compared over time besides across units. Let y_{it}^{*} be the maximum output of the *i*th mine at time, *t*. It is achievable only if all available factors of production are used most efficiently. The efficient level of output, y_{it}^{*}, defined as the predicted frontier output from a frontier production function, may be expressed as

$$y_{it}^{*} = f(x_{it};\beta)\exp(v_{it}) \tag{1}$$

where, x_{it} denotes a vector of factor inputs for the *i*th mine with β being parameters to be estimated, and v_{it} is a random disturbance term independently distributed as $N(0, \sigma_v^2)$. It is stochastic in the sense that it captures random effects on frontier output beyond management control.

Under normal circumstances, efficient output cannot be directly observed. The observed output level, y_{it}, will not exceed the efficient level y_{it}^{*}, due to technical inefficiency on the part of the mine itself. These inefficiencies may include, among other things, a waste of certain resources resulting from factors such as mismanagement. If the difference between the maximum and actual outputs could be represented by an exponential factor, $\exp(u_{it})$, the actual output could be expressed as a function of the stochastic frontier output level, or

$$y_{it} = y_{it}^{*}\exp(-u_{it}) \tag{2}$$

where, u_{it} are assumed to be independently distributed as truncations above at zero of $N(\mu, \sigma_u^2)$ i.e. $u_{it} \sim N^{+}(\mu, \sigma_u^2)$. Given a proper functional form, therefore, the unobserved stochastic frontier production function could be estimated using the log likelihood method.

Following, Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977), the production function to be estimated is expressed as

$$y_{it} = f(x_{it};t,\beta)\exp(v_{it} - u_{it}) = f(x_{it};t,\beta)\exp(\varepsilon_{it}) \tag{3}$$

where, ε_{it} is the disturbance term composed of v_{it} and u_{it}, (i.e. $\varepsilon_{it} = v_{it} - u_{it}$), which are independent from each other and the time trend, *t*, is used to capture the technological change. The exponential factor, $\exp(u_{it})$ actually measures technically efficiency, i.e. TE_{it}, for the mine concerned. It is defined as the ratio of the actual and maximum output levels, or

$$TE_{it} = y_{it} / y_{it}^{*} \tag{4}$$

B. Technical/Productive Efficiency

To estimate the technical efficiency one needs to know the functional form in equation (3). The most common functional form used in the literature is the translog function. We have panel data on *m* mines over *T* time periods, and the translog production frontier of the *i*th mine can be expressed as:

$$\begin{aligned} \ln(y_{it}) = \beta_0 &+ \beta_k \ln k_{it} + \beta_l \ln l_{it} + \beta_t t \\ &+ \frac{1}{2}\left[\beta_{kk}(\ln k_{it})^2 + \beta_{ll}(\ln l_{it})^2 + \beta_{tt} t^2\right] \\ &+ \beta_{kl} \ln k_{it} \ln l_{it} + \beta_{kt} t \ln k_{it} + \beta_{lt} t \ln l_{it} \\ &+ v_{it} - u_{it}, \end{aligned} \tag{5}$$

where, $i = 1, 2, 3, \ldots, 12$, and $t = 1, 2, 3, \ldots, 15$, represent the number of mines and time periods, respectively.

Battese and Coelli (1988) derived the maximum likelihood function of a time invariant stochastic production frontier panel model. In practice it seems natural to relax the assumption that technical efficiency is time invariant. Battese and Coelli (1992) proposed a stochastic frontier production model for panel data permitting technical efficiency to vary over time. They define u_{it} to accommodate the time-varying assumption as follows:

$$u_{it} = \eta_t u_i \tag{6}$$

where, $\eta_t = \exp\{-\delta(t - T)\}$, and δ is a parameter that plays an important role in the behavior of technical efficiency over time. They note that if $\delta > 0$, TE rises at a decreasing rate, if $\delta < 0$, TE declines at an increasing rate, and if $\delta = 0$, TE remains the same. However, we believe that the dynamics of the mining industry do not exhibit monotonic patterns in technical efficiency over time. Therefore, to capture the time-varying nature of efficiency without restricting it to be monotonic, we use the following specification proposed by Battese and Coelli (1995):

$$u_{it} = \delta_0 + \delta_1 t + w_{it} \tag{7}$$

where, the random variable, w_{it}, is defined by the truncation of the normal distribution with mean = zero and variance $=\sigma_w^2$. Thus, following Battese and Coelli (1995), we estimated technical/productive efficiency (PE) by the minimum mean square error predictor, i. e.

$$TE_{it} = E\left[\exp(-u_{it})\middle|\varepsilon_{it}\right] \tag{8}$$

$$= \left[\frac{1-\Phi(\sigma_* - (\tilde{\mu}_{it}/\sigma_*))}{1-\Phi(-\tilde{\mu}_{it}/\sigma_*)}\right]\exp\left\{-\tilde{\mu}_{it} + \frac{1}{2}\sigma_*\right\}$$

where,

$$\tilde{\mu}_{it} = (\sigma_*^2\varepsilon_{it} + \mu_t\sigma_v^2)/\sigma^2 \quad , \quad \mu_t = \delta_0 + \delta_1 t\,, \quad \sigma_*^2 = \frac{\sigma_u^2\sigma_v^2}{\sigma^2} \text{ and } \sigma^2 = \sigma_u^2 + \sigma_v^2$$

Note that this specification allows efficiency to vary over time but the changes in efficiency may not be monotonic.

Next, to determine the determinants of inefficiency, estimated mine level inefficiencies are regressed against a set of selected variables, i.e.

$$\text{TIE}_{it} = \alpha_0 + \alpha_1 z_{1,it} + \alpha_2 z_{2,it} + \ldots.. + \alpha_g z_{g,it} + \xi_{it} \tag{9}$$

where TIE_{it} is the technical inefficiency of mine *i* at time *t* and is defined as $\text{TIE}_{it} = 1 - \text{TE}_{it}$ and $z_{1,it}$, $z_{2,it}\ldots z_{g,it}$ are *g* independent variables, α_0, $\alpha_1\ldots\alpha_g$, the parameters to be estimated, and ξ_{it} is the error term which is assumed to be independent, identically distributed as normal with mean = 0 and variance = σ_ξ^2. Thus, from equation (4) we obtain

$$\text{Maximum Possible Output} = \text{Observed Output}/\ TE_{it}\,. \tag{10}$$

C. Productivity Analysis

By using the stochastic frontier methodology, the output growth of each mine is decomposed into three components: output growth due to growth in inputs, output growth due change in technical efficiency, and output growth due to technological progress. Thus, when we observe that a mine has increased its productivity from one year to the next, the improvement need not have been from efficiency improvements alone, but may have been due to technological change, or due to the exploitation of economies of scale (i.e. due to change in inputs) or, from a combination of all three factors.

Following Mahadevan and Kalirajan (1999, 2000), the decomposition of output growth can be illustrated graphically with the help of Figure 2.

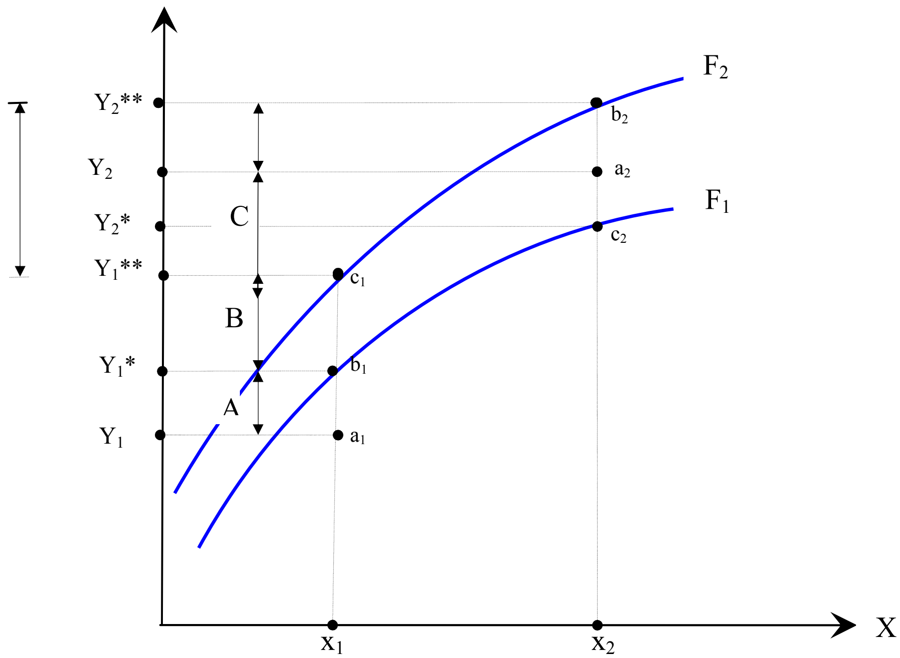


Figure 2. Graphical Representation of Output Growth Due to Technological Progress, Efficiency and Input Growth

Let us assume that the mine faces production frontiers F_1 and F_2 in periods 1 and 2 respectively. The frontier in period 2 shifts to F_2 due to technological progress. If the given mine keeps up with technological progress, more output is produced from the same level of inputs. The technological progress is measured by the distance between the two frontiers, i.e. F_2 - F_1 evaluated at x_1, or Y_1^{**}- Y_1^{*} in Figure 2. For a technically efficient mine, output would be Y_1^{*} in time period 1 using input level x_1, and Y_2^{**} in period 2 using input level x_2.

Due to technical inefficiency in production, the mine may be producing output Y_1 in period 1 using input x_1, and Y_2 in period 2 using input x_2. Technical inefficiency in terms of loss of output is given by the distance between the frontier output and the actual outputs of a mine. Technical efficiency, TE_1, in period 1 measures the vertical distance between Y_1 and Y_1^{*}. In period 2, technical efficiency, TE_2, measures the vertical distance between Y_2 and Y_2^{**}. So the contribution to output growth due to change in technical efficiency between the two periods is measured by the difference between TE_2 and TE_1, i.e. $TE_2 - TE_1 = \left(Y_2^{**} - Y_2\right) - \left(Y_1^{*} - Y_1\right)$. If this value is positive, it implies an improvement in the mine's technical efficiency. The output growth between the two periods due to input growth can be measured by $\left(Y_2^{**} - Y_1^{**}\right)$ along the frontier 2.

Thus, the total output growth can now be decomposed into three components, i.e. output growth due to change in technical efficiency, output growth due to technological progress and the output growth due to input growth.

The output growth between periods 1 and 2 = $Y_2 - Y_1$

$$
\begin{aligned}
&= A + B + C \\
&= \left(Y_1^* - Y_1\right) + \left(Y_1^{**} - Y_1^*\right) + \left(Y_2 - Y_1^{**}\right) \\
&= \left(Y_1^* - Y_1\right) + \left(Y_1^{**} - Y_1^*\right) + \left(Y_2 - Y_1^{**}\right) + \left(Y_2^{**} - Y_2^{**}\right) \\
&= \left(Y_1^* - Y_1\right) + \left(Y_1^{**} - Y_1^*\right) - \left(Y_2^{**} - Y_2\right) + \left(Y_2^{**} - Y_1^{**}\right) \\
&= \left\{\left(Y_1^* - Y_1\right) - \left(Y_2^{**} - Y_2\right)\right\} + \left(Y_1^{**} - Y_1^*\right) + \left(Y_2^{**} - Y_1^{**}\right) \\
&= \dot{TE} + \dot{TP} + \dot{y}_x^* \qquad (11)
\end{aligned}
$$

where $\dot{y}_x^*$ equals change in output due to input growth; $\dot{TP}$ equals change in output due to technological progress, and $\dot{TE}$ equals change in output due to change in technical efficiency.

RESULTS AND DISCUSSION

Task 1: Data Description and Collection

A. Primary Variables

Since coal prices for individual mines are of a proprietary nature and vary widely across the industry, it is more appropriate for this productivity study to use physical units of output rather than value measures. Following Boyd (1984), the output used in this study is clean tons shipped, using US standard ton units. For the purposes of this study, we consider all output to be of a homogeneous nature, as concern is primarily with the quantity produced for sale as opposed to the value of the product. The net output from each mine is recorded in annual tons F.O.B the mine site as reported to the Illinois Department of Natural Resources (IDNR) on the Annual Operator's Report. Alternatively, run-of-mine (ROM) product was considered as the output variable, but inconsistencies in reporting methods proved detrimental to the analysis, so it was subsequently rejected. Thus, the output measure used in the translog production frontier is tons F.O.B. the mine site.

In this study, labor input is measured in man-hours and is compiled from the following four categories: mining personnel involved in the actual mining process, prep plant personnel, administrative personnel, and others including shop employees as well as contract personnel. Previous work in this area had used "miner days" as the labor input in their production function (Myers et al, 1981). In view of the complex work schedules that have evolved within the mining industry, such as 10 hour shifts and continuous manning of face equipment, actual man hours provides a much more accurate input to the production function.

Capital is defined as the equipment used in the production process. Because there is no systematic data at the State level, concerning the value of capital used in the mining industry, it was necessary to explore alternative methods to capture this data for the present project. Following previous studies that have been done for the mining industry in the U.S and other countries, we elected to use horsepower as a proxy for capital. Leser (1955), in his study of production functions in British coal mining, justified using horsepower by arguing that it captures quality changes in capital that are not revealed by traditional accounting methods and that it gives a measure of the physical productivity of capital. Kulshreshtha and Parikh (2002) also used machine horsepower in their study of efficiency and productivity in the Indian mining sector. There are some objections to using horsepower on the grounds that the trend of technological development may increase performance of mining machinery without increasing horsepower. This objection is not of great concern because it appears that changes in horsepower have accompanied the evolution of modern mining machines.

To develop the horsepower values for each mine under evaluation, data on the type and number of continuous miners and long-wall shearers taken from the IDNR Annual Operator's Reports is converted. We obtained the horsepower rating of each type of machine through research and contacts with the original equipment manufacturers (OEMs). In cases where the specific brand of machine was omitted from the IDNR report, an industry wide average for the type of machine is used for the time period in question. Our estimation uses total horsepower of coal cutting machines employed at the mine as an input to the production function.

B. Secondary Variables

There are a myriad of geological conditions that contribute to management's decisions concerning extraction methodology and hence the production process. Coal seam thickness in inches and depth to seam in feet are considered as variables contributing to efficiency/inefficiency.

As a mine gets older and spreads out, management must adapt to meet the additional burdens of increasing distances to the coal face. Increased travel time to deploy manpower to the coal face is required and infrastructure must increase to meet the greater transportation requirements for getting coal to the surface and supplies to the face. To incorporate the impact on efficiency that can occur as the mine advances, we include the age of the mine as a secondary variable in this study. Age is interpreted as years in operation.

In the mining industry there is considerable concern with safety issues as evidenced by the resources expended to train personnel and comply with the demands of regulatory agencies. To reflect the relationship between safety and efficiency, data on injury frequency rate is considered as an input to the production of coal in our study. Injury frequency rate as defined by the IDNR is calculated as the number of reportable injuries divided by man-hours worked and is reported on an annual basis.

There has been much debate throughout the industry concerning the impact union representation of the mining work force has had on production. To investigate the impact of unionization on production efficiency a dummy variable for unionization is also considered as a secondary variable.

We also included preparation plant capacity in tons per hour as a secondary variable in our study. We expect this variable to be a significant factor contributing to the efficiency of the mine.

C. Data Collection

This study required cross-section data on mines in Illinois that were in continuous operation for an extended time period. After initial review of the mines that were operational in 2003, we compiled a list of 13 underground and 4 surface operations. Based on this information, it was determined that data across a 10 to 15 year time span would be necessary to make the appropriate estimations of the production frontier.

A thorough search of the publicly available information which includes the U.S. Bureau of Energy, U.S Economic Census, U.S. Mine Health and Safety Administration (MSHA), U.S. Bureau of Labor, and Illinois Department of Natural Resources Office of Mines and Minerals (IDNR-OMM), as well as many other sources proved that IDNR-OMM was the richest public source of Illinois mining data available.

IDNR provided access to the Annual Mine Operator's Reports, which are maintained on file in the Benton office.[1] From these reports, data from 1989 to 2003 was collected and electronically cataloged. We were able to determine that among the original 17 mines, two of the surface mines and one of the underground mines had not been in operation a sufficient length of time to be useful for our study so they were eliminated. Due to the fundamental differences in production methods, surface operations must be evaluated separately from the underground operations. With only two surface mines active in Illinois during the study time span, data was found to be insufficient to evaluate surface operations separately. The final cross section of mines for this study consists of 12 underground operations across a 15 year time span beginning in 1989 and running through 2003.

To estimate a production function and evaluate the efficiency of an industry, it is important to have quality data from which to build the model. It is in this spirit that we designed a six-point questionnaire to be sent to the mines in an effort to augment the data compiled from other sources. Of primary concern were capital expenditures of the mines for the time period under study. This survey questionnaire was distributed to the mines identified as operational during the time period. After extensive networking within the industry by our team, as well as by the ICCI project manager, this avenue was abandoned due to lack of participation on the part of mine operators. At the time this report was

[1] We would like to acknowledge the assistance provided by Michael Woods, Division Director IDNR Office of Mines and Minerals and Art Rice of the Benton office for their assistance and providing access to the report archives.

prepared, we had received completed questionnaires from only two of the mines with a commitment to participate from a third.

Task 2: Data Analysis

Due to the dynamic nature of the modern mining industry created by shorter product contract cycles and other factors, it is not uncommon for mining at a particular operation to be halted for extended periods of time. Where data is found missing during the time period under consideration, we have used an average based on the previous and following year to estimate the missing data. If a mine had no production in years at the beginning or end of the period, the following or previous year data is extended to estimate the missing data. Output, capital and labor data were plotted over the years for each mine to carefully look for any outliers.

Task 3: Efficiency Analysis

A. Estimation:

Following Battese and Coelli (1995), maximum likelihood estimation was used to simultaneously estimate equations (5) and (7). We used FRONTIER 4.1 software to estimate the model and obtain technical efficiency estimates. The parameter estimates of the translog production model along with their standard errors are reported below in Table 1.

Table 1: Parameter Estimates for Equations (5) and (7)

Variable Description	Variable Label	Estimates	Std. Error	t-value
Intercept	β_0	-13.1923	1.3833	-9.5366*
ln(K)	β_k	-2.0150	0.8453	-2.3839*
ln(L)	β_l	4.9086	0.5685	8.6340*
t	β_t	-0.5040	0.0867	-5.8115*
$[\ln(K)]^2$	β_{kk}	0.7372	0.2727	2.7036*
$[\ln(L)]^2$	β_{ll}	-0.1468	0.1386	-1.0594
t^2	β_{tt}	-0.0052	0.0020	-2.5902*
ln(K)*ln(L)	β_{kl}	-0.3012	0.1831	-0.6451
T*ln(K)	β_{kt}	-0.0187	0.0097	-1.9296**
T*ln(L)	β_{lt}	0.0561	0.0089	6.2985*
Intercept	δ_0	0.2654	0.1254	2.1158*
Trend	δ_1	0.0102	0.0106	0.9643
Variance of Ineff.	σ_u^2	0.0740	0.0178	4.1653*
γ	$\sigma_u^2/(\sigma_u^2+\sigma_v^2)$	0.9989	0.0092	108.1770*

* indicates significance at 5% level. ** indicates significance at 10% level.

Out of ten parameters in the translog function (equation (5)), seven are statistically significant at the 5% level of significance and one parameter is significant at the 10% level of significance. The coefficients of t and t^2 both are negative and statistically significant indicating decreasing technological change at a decreasing rate. The parameter, γ, denotes the variance of the inefficiency component of the error term, σ^2_u, divided by total variance, $(\sigma_u^2+\sigma_v^2)$. It is nearly one and statistically significant suggesting that the majority of variation comes from inefficiency and thus inefficiency was present in production.

B. Technical/Productive Efficiency

By using equation (8), and the parameter estimates reported in Table 1, the technical efficiency of each mine at each time period is estimated. These estimates are reported in Table A.1 in the Appendix. Using equation (10) the maximum feasible output for each mine at each time point is also obtained. These detailed results are also reported in the same Table A.1 in the Appendix. It is worth noting that even in a perfect world the potential maximum feasible output may not be attainable in any industry. However, in the real world the attainable output should be close to the potential output.

Average technical efficiency, total output, potential output based on our frontier model, and output loss due to inefficiency for the twelve mines studied are reported by year in Table 2. The output loss is obtained by subtracting the observed output from the potential output.

Table 2: Yearly Average Efficiencies and Output Loss Due to Inefficiencies

Year	Average Efficiency	Industry Output	Potential Output	Output Loss
1989	0.724	18,570,348	25,654,876	7,084,529
1990	0.698	19,838,404	28,438,899	8,600,495
1991	0.703	21,620,708	30,749,796	9,129,088
1992	0.722	22,712,318	31,453,644	8,741,326
1993	0.677	21,456,798	31,712,108	10,255,310
1994	0.686	24,894,902	36,289,641	11,394,739
1995	0.686	25,882,303	37,755,523	11,873,220
1996	0.712	27,243,318	38,275,546	11,032,228
1997	0.666	26,998,861	40,522,475	13,523,614
1998	0.740	28,117,956	38,019,362	9,901,406
1999	0.709	29,926,823	42,218,694	12,291,871
2000	0.668	29,416,708	44,035,666	14,618,958
2001	0.654	27,832,900	42,531,115	14,698,215
2002	0.658	26,186,723	39,804,616	13,617,893
2003	0.633	25,953,074	41,014,753	15,061,679
Total	0.689*	376,652,142	548,476,713	171,824,571

* denotes the overall average of all mines over all years.

Mean technical efficiency for all twelve underground mines over the entire fifteen year study period is 0.69. The highest yearly efficiency, 0.74, was achieved in 1998 and the lowest, 0.63, in 2003. The total output produced by these mines during the period of the study was 376.6 million tons. However, due to inefficiency, the mines lost 171.8 million tons of coal production during the 15-year span. The model indicated that the twelve mines had the potential to produce a total of 548.5 million tons of coal during this period. Note that in 2003, the average efficiency of the industry was 63.3% and the output loss is the highest at just over 15 million tons. It is obvious that any improvement in productive efficiency would equate to a substantial increase in output for the underground mining industry.

To provide some perspective on the effect a small change in productive efficiency might have on the industry, consider just a two percentage point increase in average efficiency, i.e. from 68.9% to 70.9 %. The annual loss of output due to inefficiency would decrease by approximately 1.03 million tons per year. At an average price of 25 dollars per ton, this would translate to nearly 386 million dollars of revenue gain for the mining industry for the 15-year span we have studied.

Average (over 15 years) technical/productive efficiency for each of the twelve mines along with their average output-labor and output-capital ratios are reported in Table 3. Table 3 also ranks the twelve mines in three different tier groups based on efficiency.

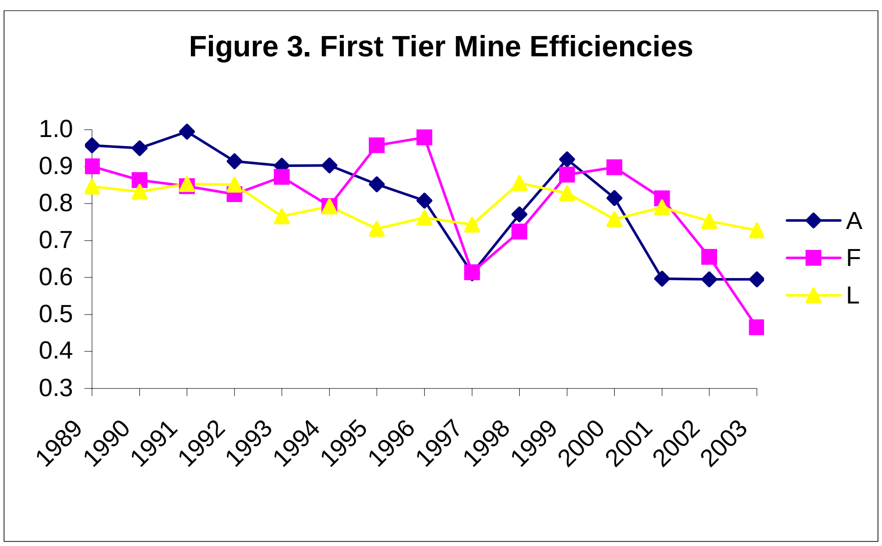
Table 3: Technical Efficiency of Individual Mines

Rank	Mine ID.	Average	Output/Labor	Output/Capital
First Tier				
1.	A	0.812	5.48	852.83
2.	F	0.806	4.26	652.22
3.	L	0.792	4.59	534.27
Second Tier				
4.	G	0.763	4.60	795.50
5.	J	0.739	4.20	413.22
6.	H	0.702	4.12	650.79
7.	D	0.690	4.32	543.33
Third Tier				
8.	I	0.650	3.40	426.98
9.	K	0.637	3.12	417.43
10.	E	0.590	3.63	434.25
11.	C	0.582	3.50	517.70
12.	B	0.506	2.71	360.34

As noted earlier, efficiencies for each individual mine, their output-labor and output-capital ratios, potential output, and loss in output for each year are reported in Table A.1 in the Appendix. The highest ranked mine is around 81% efficient on average while the lowest ranked mine is near 50% efficient on average. Statistically it is not meaningful to differentiate between mines to such a small degree that we can say, for example, that A is more efficient than L. For this reason, we have subdivided the twelve mines into three tiers that are different from one another in terms of technical efficiencies.

The first tier represents those operations that exhibit the highest technical efficiency of the twelve operations studied. Average efficiency among these mines is 80.3 %. The average of the second tier is 72.4%. The third or lowest tier of mining operations average 59.3% efficient. The average output produced per man hour is 4.8 tons by the first tier mines, 4.3 tons by the second tier mines, and 3.3 tons by the third tier mines. Average output produced per unit of horsepower is 679.8 tons by the first tier mines, 600.7 tons by the second tier mines, and 431.3 tons by the third tier mines.

Figures 3, 4, and 5 plot the efficiencies across time for each mine within their respective tier ranking. As can easily be seen in Figure 3, no one mine exhibits the highest efficiency in every year. If we examine the graph in detail, it is readily apparent that both mine A and mine F experienced a low in technical efficiency in 1997. The output–labor and output-capital ratios for these mines also reveal that these ratios are at or near their lowest points in 1997. In Figure 4, it appears as though there could be a slight trend of increasing efficiency in the second tier of mines across the time span under study. Figure 5 on the other hand, indicates there is a slight trend of decreasing efficiency among the lower tier of mining operations within the State.



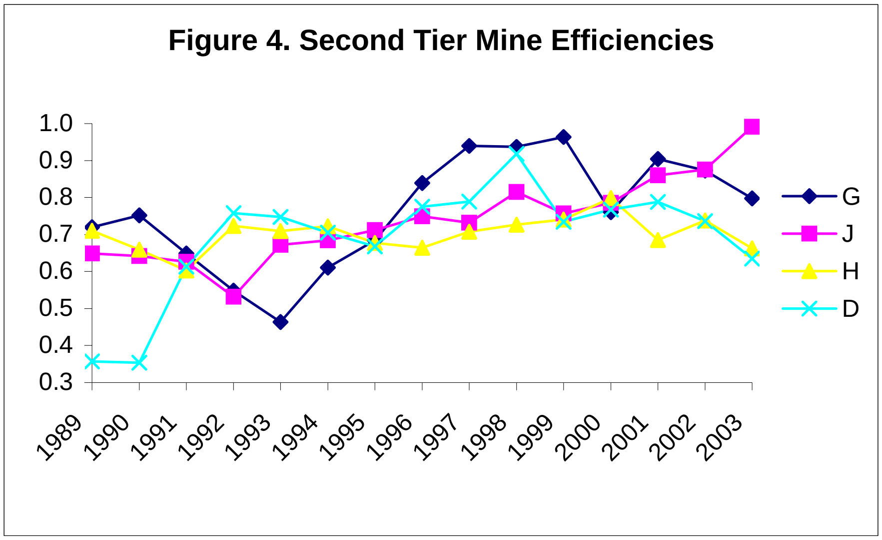


Figure 4. Second Tier Mine Efficiencies

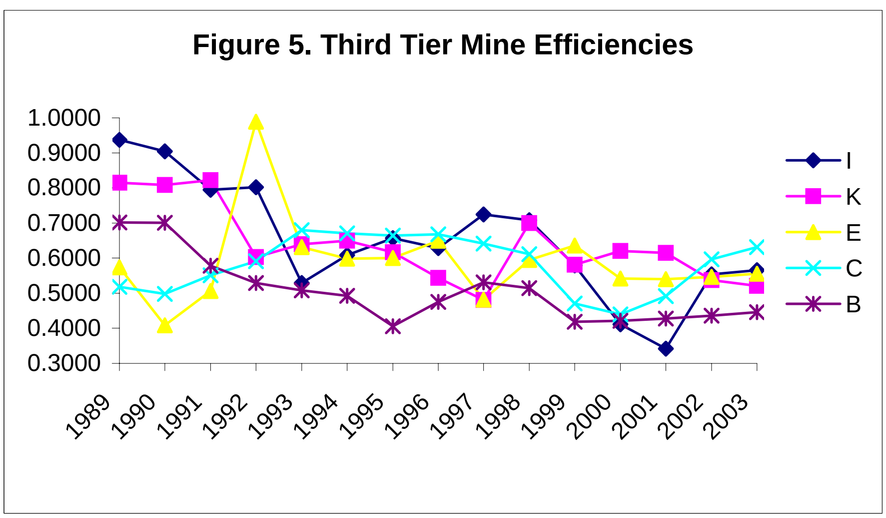


Figure 5. Third Tier Mine Efficiencies

C. Determinants of Inefficiency:

To investigate possible determinants of technical inefficiency, several variables are introduced for consideration. For this study, seam thickness in feet, depth to seam in feet, injury frequency rate, injury severity rate, ratio of administrative labor to total labor, age of the mine, union affiliation, and preparation plant capacity are employed to explore the determinants of inefficiency. Estimating equation (9) gives the coefficient and statistical significance of each variable as shown in Table 4.

Table 4: Parameter Estimates of Inefficiency Regression

Variable Description	Variable Label	Parameter Estimate	t – Value
Intercept	Intercept	0.36687	4.33*
Thickness	Z1	-0.02604	-1.89**
Depth	Z2	0.0001222	2.2*
Injury Frequency	Z3	0.00364	2.27*
Injury Severity	Z4	-0.00000	-1.14^
Admin./Total Labor	Z5	0.18903	0.75^
Age	Z6	0.00526	2.86*
Prep Plant	Z7	-0.00181	-5.29*
Union	Z8	0.02393	0.71^

** significance at 10% level, * significant at 5% level, ^ not significant.

From Table 4 we note that the coefficient for injury severity rate is not significantly different from zero indicating the seriousness of injuries has little if any influence on inefficiency. The ratio of administrative labor to total labor has a positive coefficient but is not statistically significant. Administrative labor is a very small portion of the overall labor employed in the mining process, which could account for the insignificance of the Z5 variable. The Z8 variable indicates whether the workforce of a mine has union representation or not. The coefficient of Z8 is not significant at all.

Seam thickness and depth to seam are both measurable geological inputs that are considered. Thickness is negatively related with inefficiency, which is consistent with intuition. The negative sign of the thickness variable coefficient implies that as seam thickness increases, inefficiency decreases, also meaning efficiency increases.

Intuitively we would expect depth to seam to be positively correlated with inefficiency. This is in fact the case. The coefficient of depth to seam is positive and statistically significant which means as depth increases, inefficiency increases. Thus, the greater the depth to the coal seam, the lower the efficiency.

Injury frequency rate can be considered a gauge of the prevailing safety environment at a mine. The coefficient of injury frequency rate is 0.004 and is statistically significant at the 5% level. This positive relationship between workman injuries and inefficiency is of no surprise. Clearly, safe work practices and efficiency go hand in hand. Thus, as the injury frequency rate increases, inefficiency increases and efficiency decreases. Older operations (mines which have been in operation for longer periods of time) should be less inefficient if we were to accept the notion that firms learn over time. Another source explanation for this conclusion *a priori* is that the older the mine, the thicker the seam, as is evident from a positive and significant correlation between seam thickness and age of mine. However, regression analysis reveals that the relationship between age and inefficiency is a positive. The estimated coefficient of 0.005 for the age variable is statistically significant at the 5% level. This result can be explained by the rapid evolution of machines and methods that has occurred in the mining industry. Mines of younger vintage were developed using knowledge of these newest innovations resulting in increased efficiency. We can also presume that as mines mature, travel distances to the coal face increase, requiring additional resources to transport labor and materials in and production out.

Preparation plant capacity is negatively related with inefficiency and significant at the 1% level. The estimated coefficient is –0.002. Installing a preparation plant represents a large capital investment for a mine and the higher the capacity, the greater the investment. Explanation of the strong relationship between larger preparation plants and greater efficiency may be found in the idea that companies that elect to build initial overcapacity into the plant have more flexibility in choosing extraction methodology and adapting to increased underground production levels. Thus, the negative sign of the prep plant capacity variable coefficient means as the capacity of the prep plant increases, technical inefficiency decreases and efficiency increases.

At this point we have exhausted all of the publicly available data series for the mining industry in Illinois. Obtaining further insight into possible determinants of inefficiency will likely require proprietary information and participation of a sizable cross section of mine operators in Illinois.

Tasks 4, 5 and 6: Productivity Analysis

There are different ways of analyzing the productivity of a firm. Different authors use different approaches. Some productivity analysis methods are more appropriate for one industry than another industry. When this research proposal was written, several different ways of looking at productivity analysis were explored. Due to data availability and to avoid complexity in presenting the productivity analysis, uncertainty analysis and Malmquist productivity index are not reported as proposed. To make productivity analysis results more understandable to mine operators, only total factor productivity (TFP) change results along with output growth results are reported.

The conventional growth accounting approach decomposes output growth as

Output Growth = TFP Growth + Input Growth

where TFP is total factor productivity growth. The growth accounting approach assumes that resources are used efficiently and that TFP growth can only emanate from technological progress. The Stochastic Frontier productivity approach agrees with the accounting approach but goes further to decompose TFP growth into

TFP Growth = Technological Progress + Change in Technical Efficiency

Thus, we decompose the output growth into the following components:

Output Growth = Technological Progress + Change in Technical Efficiency
+ Change in Output Due to Input Growth (12)

The results of decomposition of output growth by using equation (12) for each year and for each of the twelve mines are reported in Table 5.

Table 5: Decomposition of Output growth

Time period	Output growth	Due to Input growth	TFP growth	Due to Change in TE	Due to TP
1989-1990	0.0855	0.0176	0.0679	-0.0260	0.0939
1990-1991	0.0641	0.0046	0.0595	-0.0297	0.0892
1991-1992	-0.0230	-0.0490	0.0260	-0.0560	0.0820
1992-1993	0.0088	-0.0208	0.0296	-0.0442	0.0737
1993-1994	0.0901	0.0531	0.0370	-0.0297	0.0667
1994-1995	0.1940	0.0327	0.1613	0.0962	0.0651
1995-1996	0.0539	-0.0435	0.0975	0.0382	0.0592
1996-1997	-0.1368	-0.0737	-0.0631	-0.1157	0.0525
1997-1998	0.0643	-0.0513	0.1156	0.0730	0.0426
1998-1999	0.1001	0.0748	0.0253	-0.0076	0.0329
1999-2000	0.0595	0.0533	0.0062	-0.0302	0.0364
2000-2001	-0.0501	-0.0439	-0.0062	-0.0404	0.0342
2001-2002	-0.0880	-0.0460	-0.0420	-0.0692	0.0272
2002-2003	-0.0431	0.1305	-0.1737	-0.1934	0.0198
Average	0.0271	0.0027	0.0244	-0.0310	0.0554

From 1989 to 2003, output growth for the twelve mines has been negative between 1991/1992; 1996/1997; 2000/2001; 2001/2002; and 2002/2003 years and positive the remainder of the time. The negative growth during these years has been due to negative growth in inputs and due to negative changes in technical efficiencies. The technical efficiency change has been negative in eleven out of fourteen years. Input growth at the twelve mines has been negative in seven out of fourteen years. The rate of technological progress has been decreasing over the entire time span. In other words, improvement in technology is slowing down. The falling trend of technological progress for the coal industry (this reference is only to the twelve mines studied here) indicates that there are limits to the use and access of newer and more advanced technology in mining activities.

Next, output growth of individual mines for each year is reported in Table A.2 in the Appendix. The average (over all years) output growth of each mine is reported in Table 6. From Table 6, we note that three out of twelve mines have negative output growth. This is due to both negative input growth and negative change in technical efficiency. The average (over all years) technological progress of all mines has been positive and varied from 1% to 5%. In eight mines we observed negative change in technical efficiencies and in seven mines we note negative input growth. Thus, in seven out of twelve mines, output growth is affected by negative input growth and/or negative efficiency growth.

Table 6: Decomposition of Output Growth of Individual Mines

Mines	Output growth	Due to Input growth	TFP growth	Due to Change in TE	Due to TP
A	0.0541	0.0767	-0.0226	-0.0340	0.0114
B	-0.0526	-0.0420	-0.0106	-0.0323	0.0217
C	0.0237	-0.0214	0.0451	0.0142	0.0310
D	0.1551	0.1039	0.0513	0.0411	0.0101
E	0.0819	0.0665	0.0154	-0.0024	0.0178
F	0.0542	0.0320	0.0222	-0.0472	0.0694
G	0.0356	-0.0167	0.0523	0.0073	0.0450
H	0.0028	-0.0296	0.0325	-0.0049	0.0374
I	-0.0280	-0.0466	0.0187	-0.0361	0.0548
J	0.0340	-0.0235	0.0575	0.0307	0.0268
K	-0.0464	-0.0685	0.0221	-0.0320	0.0541
L	0.0362	0.0209	0.0153	-0.0108	0.0261
Average	0.0292	0.0043	0.0249	-0.0089	0.0338

Task 7: Output Elasticities

Evaluating elasticities was not part of the original proposal but while analyzing output growth results, it was decided to add this extra task to the study. Output elasticities of labor and capital help us analyze in depth the role of capital and labor in production.

The change in output due to input growth can be captured through the elasticities of output with respect to inputs, i.e. elasticity of output with respect to capital (K), e_k, elasticity of output with respect to labor (L), e_l, and total elasticity, $e = e_k+e_l$. A value of $e = 1$ indicates constant returns to scale. In other words, by changing K and L by 1% will increase output by 1%. A value of $e > 1$ indicates increasing returns to scale, or increasing K & L by 1% will increase output by more than 1%. A value of $e < 1$

indicates decreasing returns to scale, or increasing K & L by 1% will decrease output by less than 1%. Total output elasticity describes the percentage change in output that will occur if both capital and labor changed by 1%.

Table 7 below summarizes the average elasticities for all the twelve mines for each year. The mean total output elasticity is 0.915. This means that on average, if capital and labor increases by 1%, output will go up by 0.915%. It can be seen that total output elasticity for the industry has been increasing over the course of this study.

Table 7: Output Elasticities for the Industry

Year	Total elasticity	Capital elasticity	Labor elasticity
1989	0.6306	-0.0009	0.6314
1990	0.6785	0.0088	0.6697
1991	0.6949	-0.0125	0.7074
1992	0.7461	0.0079	0.7381
1993	0.7762	-0.0639	0.8401
1994	0.7945	-0.0652	0.8597
1995	0.8746	-0.0557	0.9302
1996	0.9187	-0.0682	0.9870
1997	0.9346	-0.0949	1.0295
1998	1.0490	-0.0137	1.0627
1999	1.0195	-0.1118	1.1313
2000	1.0536	-0.1264	1.1800
2001	1.1197	-0.1176	1.2373
2002	1.2038	-0.0856	1.2894
2003	1.2255	-0.1112	1.3366
Average	0.9146	-0.0607	0.9754

To better understand the respective roles of capital and labor, we examine elasticity of capital and elasticity of labor separately. From Table 7 we note that the output elasticity of capital for the industry displays a downward trend. The magnitude of capital elasticity is very small, ranging from –0.001 in 1989 to –0.111 in 2003 and averaging –0.061 for the 15-year period being studied. Small negative capital elasticity may appear counter intuitive until industry-specific circumstances are evaluated. The Illinois mining industry, as a whole, experiences only very small capital changes from year to year in the absence of new mines entering and mature mines exiting. Our study encompasses only mines in continuous operation from 1989 to 2003. Hence there are only relatively small changes in capital at the industry level. The volatile nature of the market for coal requires that mines adapt by rapidly adjusting production. This is often accomplished via a reduction in the number of hours machinery is used, not by removing machinery from the mine. In this scenario, it is clear that adding even more capital to the process would not augment production and may even be detrimental. On the other hand, when the market is more favorable, production can be gained by increased utilization of the capital that is already in place.

To employ capital machinery more fully requires additional labor. Table 7 indicates that the output elasticity of labor is positive and monotonically increasing throughout the study implying labor has become more productive. Mean labor elasticity for the mining industry is 0.975. During the time period from 1989 through 2003, annual output of the twelve mines studied increased from 18.5 million tons to 25.9 million tons while annual labor hours decreased from 6.8 million to 6.5 million. Though mining labor has decreased, it has become more significant to the production process as evidenced by the increasing output elasticity of labor.

The output elasticity with respect to capital and labor for individual mines (averaged over all years) are reported in Table 8.

Table 8: Average Elasticities for Individual Mines

	Capital		Labor		Total	
Mine ID.	*Elasticity*	*Rank*	*Elasticity*	*Rank*	*Elasticity*	*Rank*
A	-0.423	12	1.291	1	0.868	9
B	-0.178	10	1.111	3	0.933	6
C	-0.162	9	1.049	5	0.888	8
D	-0.228	11	1.188	2	0.960	4
E	-0.143	7	1.109	4	0.966	3
F	0.262	1	0.590	12	0.852	11
G	-0.136	6	0.954	8	0.818	12
H	-0.155	8	1.010	6	0.856	10
I	0.228	2	0.715	11	0.943	5
J	0.097	4	0.931	9	1.028	1
K	0.127	3	0.767	10	0.894	7
L	-0.019	5	0.991	7	0.972	2

Output elasticity of capital ranges from –0.423 for mine A to 0.262 for mine F and the output elasticity of labor varies from 0.590 for mine F to 1.291 for mine A. It is important to note that mines which exhibit slow growth in technological change have lower elasticity of capital. To establish how the data in Table 8 may be used to evaluate the production process at a mining operation, two examples are presented.

Mine A has average capital elasticity of –0.423 and average labor elasticity of 1.291. We know from previously estimated total factor productivity that this mine displays a positive technology change reflecting the accumulation of capital in almost every year. From this information it can be concluded that production may have been enhanced more if this mine would have concentrated on labor-intensive output expansion.

Mine F is one of the most efficient operations in the State and is very large in terms of annual output. This mine also exhibited the highest rate of technological change among the mines studied. Combining these factors creates a dynamic in both capital and labor elasticity that is very different from other mines. Average output elasticity of capital is positive and higher than the other mines at 0.262 while average output elasticity of labor is lower than all other mines at 0.590. This operation relies heavily on capital and downtime to machinery that affects capital utilization will have greater production consequences than would be seen in other mines.

CONCLUSIONS AND RECOMMMENDATIONS

The purpose of this study was to evaluate underground coal mining efficiency from an economics point of view. There were four main objectives. First, to estimate the technical/productive efficiency of underground mines in Illinois from 1989 to 2003. Second, to shed some light on the determinants of inefficiency. Third, to decompose the output growth into technological progress, change in technical efficiency and change in output due to input growth. Fourth, to analyze the determinants of output growth.

The main findings of this study are as follows. The overall average technical/productive efficiency of all the mines considered in this study during the time period from 1989 to 2003, is 69%. This means that these mines produced 69% of the potential output they could have produced by using the same resources. The highest annual average efficiency was 74% in 1998, and the lowest was 63% in 2003. There is a clear distinction among the mines. Three mines are around 80% technically efficient. Four mines are in the 69% to 76% efficiency range. The other five mines are in the 50% to 65% range.

Besides the amount of labor and capital used in production, other factors which have contributed to inefficiency are depth to the coal seam, injury frequency rate and age of the mine.

From 1989 to 2003, year-to-year output growth for the underground coal mining industry in Illinois was negative between 1991/1992; 1996/1997; 2000/2001; 2001/2002; and 2002/2003 and positive the remainder of the time. Negative growth periods were due to negative growth in inputs and negative changes in technical efficiencies. The technical efficiency change was negative in eleven out of fourteen years. Input growth at the twelve mines studied was negative in seven out of fourteen years. The rate of technological progress has been decreasing during the study period. In other words, improvements in technology are slowing down. The falling trend of technological progress for the coal industry indicates that there are limits to the use and access of newer and more advanced technology in mining activities.

In analyzing output growth of individual mines, we note that three out of twelve mines have experienced negative output growth. This is due to both negative input growth and negative change in technical efficiency. The average (over all years) technological progress of all mines has been positive and varied between 1% and 5%. In eight mines, we observed negative change in technical efficiencies and in seven mines we noted negative input growth. Thus, output growth at seven out of twelve mines is affected by negative input growth and/or negative efficiency growth.

Finally, we note that the elasticity of output with respect to capital is negative. Basically, this implies that an increase in capital would not increase output. However, the output elasticity of labor is positive and has been increasing from 1989 to 2003. The average elasticity of labor during that time was .975. In other words, if labor (in terms of man hours) is increased 10%, output will go up by 9.75%.

Analyzing the elasticities of individual mines, we note that eight mines have negative capital elasticity ranging from –0.019 to –0.423. The other four mines have positive capital elasticity in the range of 0.10 to 0.26. Interestingly enough, it appears that in general an increase in capital would create a fall in output for some mines. On the other hand, the labor elasticity is close to or above 1.00 for nine mines and ranges from 0.60 to 0.77 for the other three mines. Thus, an increase in the input of labor would result in an equal or more than proportional increase in output.

Using this type of efficiency analysis, mining firms should be able to determine if a particular operation is performing at a level of productivity that is expected and analyze the source of its short comings. Mines should be able to use this information to adjust their mining plan and capital expenditures in order to achieve a superior level of efficiency and hence higher profitability. Using the information from this type of analysis would allow firms to discern productivity issues from cost or geological issues.

Information gained from this type of study will provide insight into the part of the mining process which management cannot control. This information could be invaluable to the application of computer simulation to the mining process. This efficiency study can be an initial step in developing measures to monitor the overall economic health of the Illinois mining industry. By knowing the source of inefficiencies within the industry, research and development can be directed to help overcome these inadequacies.

An economic model is only as good as the data that it uses. This study identified the need for a comprehensive compilation of economic data for the coal industry. Most of the data needed for the study was available but not from one source. Separate records are kept of the State and Federal level with little or no correlation between the two. Thus, it is recommended that government authorities examine how record keeping could be streamlined and consolidated into one central depository.

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APPENDIX

Table A.1: Efficiency and Output Loss for Individual Mines

Mine A

Year	Efficiency	Actual Output	Potential Output	Loss in Output	Output/ Capital	Output/ Labor
1989	0.958	777742	1589584	811842	294.15	5.27
1990	0.950	777742	1596490	818748	294.15	5.27
1991	0.995	1103447	2212345	1108898	834.68	6.20
1992	0.915	1147572	2402209	1254637	868.06	5.85
1993	0.902	1263611	2664059	1400448	955.83	6.00
1994	0.903	1341973	2828056	1486083	1015.11	6.18
1995	0.852	1445910	3142203	1696293	1093.73	6.11
1996	0.808	1451912	3249801	1797889	1098.27	5.95
1997	0.611	1433826	3779496	2345670	1084.59	4.91
1998	0.771	1537862	3532611	1994749	775.52	5.11
1999	0.920	2042397	4263196	2220799	1029.95	6.32
2000	0.815	1863959	4150811	2286852	939.97	5.67
2001	0.597	1658073	4435299	2777226	836.14	4.43
2002	0.595	1658073	4446335	2788262	836.14	4.43
2003	0.595	1658073	4442973	2784900	836.14	4.43
Average	0.812	1410811	3147271	1736459	852.83	5.48

Mine B

Year	Efficiency	Actual Output	Potential Output	Loss in Output	Output/ Capital	Output/ Labor
1989	0.701	1420683	3446235	2025552	405.91	2.77
1990	0.700	1697849	4121650	2423801	658.08	2.99
1991	0.578	1237845	3379576	2141731	407.19	2.74
1992	0.530	1189761	3436705	2246944	461.15	2.75
1993	0.508	1330466	3947571	2617105	515.68	2.76
1994	0.493	1322958	4006373	2683415	512.77	2.83
1995	0.406	506459	1753017	1246558	196.30	2.31
1996	0.475	576578	1790523	1213945	220.24	2.69
1997	0.531	891827	2572770	1680943	340.65	3.17
1998	0.514	1015531	2990667	1975136	387.90	3.18
1999	0.418	680309	2306820	1626511	259.86	2.48
2000	0.422	680309	2293278	1612969	259.86	2.48
2001	0.428	680309	2271597	1591288	259.86	2.48
2002	0.436	680309	2242108	1561799	259.86	2.48
2003	0.446	680309	2205257	1524948	259.86	2.48
Average	0.506	972767	2896257	1923490	360.34	2.71

Mine C

Year	Efficiency	Actual Output	Potential Output	Loss in Output	Output/ Capital	Output/ Labor
1989	0.518	981804	2877465	1895661	239.58	2.22
1990	0.498	981766	2951986	1970220	239.57	2.30
1991	0.551	1149074	3234882	2085808	240.34	2.83
1992	0.591	1300619	3502207	2201588	260.75	3.21
1993	0.680	1595356	3941336	2345980	530.37	3.63
1994	0.671	1643127	4091944	2448817	546.25	3.75
1995	0.664	1583427	3969004	2385577	526.41	3.87
1996	0.667	1730166	4322781	2592615	766.92	4.31
1997	0.642	1947848	4983213	3035365	863.41	4.37
1998	0.611	1326236	3497302	2171066	587.87	3.98
1999	0.471	1525263	4764333	3239070	676.09	3.40
2000	0.440	1585514	5189194	3603680	702.80	3.32
2001	0.492	1421283	4309632	2888349	630.00	3.53
2002	0.596	1504626	4028123	2523497	500.21	3.84
2003	0.631	1368273	3535459	2167186	454.88	3.86
Average	0.582	1442959	3924218	2481260	517.70	3.50

Mine D

Year	Efficiency	Actual Output	Potential Output	Loss in Output	Output/ Capital	Output/ Labor
1989	0.357	247162	939403	692241	164.34	1.97
1990	0.354	247162	946246	699084	164.34	1.97
1991	0.613	595175	1565749	970574	316.58	3.41
1992	0.757	943188	2188567	1245379	418.08	4.21
1993	0.747	1084555	2536358	1451803	721.11	4.75
1994	0.705	1204281	2913484	1709203	800.72	4.70
1995	0.668	1130730	2824065	1693335	751.82	4.53
1996	0.775	1292620	2959789	1667169	859.45	5.31
1997	0.789	1606455	3641752	2035297	534.06	4.77
1998	0.918	1557774	3254416	1696642	517.88	5.43
1999	0.735	1697843	4008893	2311050	564.44	4.61
2000	0.767	2073543	4775627	2702084	551.47	4.87
2001	0.788	2427808	5507526	3079718	645.69	5.15
2002	0.736	2117246	4992407	2875161	563.10	4.76
2003	0.635	2169104	5587527	3418423	576.89	4.27
Average	0.690	1359643	3331163	1971520	543.33	4.32

Mine E

Year	Efficiency	Actual Output	Potential Output	Loss in Output	Output/ Capital	Output/ Labor
1989	0.574	417924	1145989	728065	454.27	3.71
1990	0.408	348719	1202779	854060	379.04	2.75
1991	0.506	731051	2174935	1443884	566.71	3.24
1992	0.989	1514726	3046303	1531577	632.45	5.45
1993	0.631	1199312	3099381	1900069	500.76	3.56
1994	0.599	1092620	2917648	1825028	382.70	3.41
1995	0.601	1085257	2892004	1806747	491.07	3.65
1996	0.649	1322137	3358019	2035882	471.01	3.90
1997	0.482	1562594	4807533	3244939	629.06	3.20
1998	0.595	1901867	5100519	3198652	382.82	3.74
1999	0.636	2164503	5568639	3404136	435.69	4.09
2000	0.542	1954593	5563593	3609000	393.44	3.55
2001	0.540	1316097	3752914	2436817	264.91	3.39
2002	0.546	1316097	3725719	2409622	264.91	3.39
2003	0.555	1316097	3686535	2370438	264.91	3.39
Average	0.590	1282906	3456672	2173766	434.25	3.63

Mine F

Year	Efficiency	Actual Output	Potential Output	Loss in Output	Output/ Capital	Output/ Labor
1989	0.901	2814919	5939699	3124780	409.38	2.49
1990	0.863	3025891	6530985	3505094	402.65	2.83
1991	0.847	3552386	7746358	4193972	385.67	3.29
1992	0.825	3771940	8344713	4572773	409.50	3.49
1993	0.872	4161704	8935896	4774192	485.33	3.93
1994	0.794	4017007	9079248	5062241	497.52	3.77
1995	0.958	5609998	11467657	5857659	597.06	5.08
1996	0.979	6520342	13177818	6657476	693.95	5.28
1997	0.614	4968610	13057085	8088475	417.95	3.82
1998	0.724	5508603	13120001	7611398	490.66	4.96
1999	0.878	6516592	13937963	7421371	991.57	5.40
2000	0.898	7518829	15894877	8376048	1144.07	5.80
2001	0.814	7009349	15624690	8615341	1066.55	5.57
2002	0.656	6325203	15970942	9645739	962.45	4.71
2003	0.465	6011356	18925195	12913839	828.92	3.48
Average	0.806	5155515	11553545	6398030	652.22	4.26

Mine G

Year	Efficiency	Actual Output	Potential Output	Loss in Output	Output/ Capital	Output/ Labor
1989	0.720	1826792	4364446	2537654	809.75	2.81
1990	0.752	1981833	4617904	2636071	376.49	2.98
1991	0.649	1943278	4939300	2996022	369.16	2.64
1992	0.549	1859982	5250307	3390325	309.17	2.43
1993	0.464	1750860	5528153	3777293	291.03	2.14
1994	0.611	2141641	5647478	3505837	340.27	3.34
1995	0.684	2100655	5172851	3072196	438.55	3.87
1996	0.839	2431630	5328582	2896952	959.60	5.30
1997	0.940	2923460	6034206	3110746	1153.69	6.18
1998	0.937	2891402	5976744	3085342	879.92	5.97
1999	0.963	3056324	6228605	3172281	1206.13	6.68
2000	0.760	2678957	6204092	3525135	1057.20	5.49
2001	0.904	3200311	6742191	3541880	1262.95	6.63
2002	0.873	3268639	7012723	3744084	1289.91	6.57
2003	0.798	3008333	6779984	3771651	1187.19	6.06
Average	0.763	2470940	5710526	3239586	795.40	4.60

Mine H

Year	Efficiency	Actual Output	Potential Output	Loss in Output	Output/ Capital	Output/ Labor
1989	0.710	1751025	4216676	2465651	1067.70	3.41
1990	0.659	1727929	4349000	2621071	1053.62	3.47
1991	0.603	1728094	4594248	2866154	1053.72	3.43
1992	0.723	1887824	4499199	2611375	793.20	3.76
1993	0.709	1995661	4810659	2814998	867.68	3.97
1994	0.722	1977391	4715392	2738001	751.86	4.12
1995	0.677	1807726	4478459	2670733	511.38	3.86
1996	0.664	1796342	4500874	2704532	404.58	3.95
1997	0.707	2008790	4848706	2839916	452.43	4.32
1998	0.727	2129324	5058829	2929505	479.58	4.53
1999	0.741	2327101	5468424	3141323	524.12	4.72
2000	0.798	2442334	5502465	3060131	550.08	5.13
2001	0.685	1889486	4648301	2758815	425.56	4.36
2002	0.738	1847446	4350209	2502763	416.09	4.59
2003	0.663	1821876	4570937	2749061	410.33	4.18
Average	0.702	1942557	4710687	2768131	650.79	4.12

Mine I

Year	Efficiency	Actual Output	Potential Output	Loss in Output	Output/ Capital	Output/ Labor
1989	0.937	2470190	5105516	2635326	519.17	2.94
1990	0.904	2769306	5832905	3063599	582.03	2.92
1991	0.795	2736131	6179845	3443714	575.06	2.77
1992	0.802	3035124	6820158	3785034	744.82	3.12
1993	0.529	1404598	4059109	2654511	344.69	2.71
1994	0.609	2706334	7151262	4444928	394.11	2.97
1995	0.657	3269017	8242683	4973666	476.05	3.33
1996	0.628	3186655	8257160	5070505	383.61	3.79
1997	0.724	4083838	9724870	5641032	479.66	4.52
1998	0.708	4097120	9885057	5787937	481.22	4.67
1999	0.579	3760617	10254455	6493838	438.15	3.90
2000	0.411	2739424	9400442	6661018	336.37	2.84
2001	0.342	1951439	7663497	5712058	239.62	2.49
2002	0.553	1670050	4688177	3018127	205.07	4.02
2003	0.566	1670050	4623190	2953140	205.07	4.02
Average	0.650	2769993	7034104	4264111	426.98	3.40

Mine J

Year	Efficiency	Actual Output	Potential Output	Loss in Output	Output/ Capital	Output/ Labor
1989	0.649	1327207	3372535	2045328	293.96	2.69
1990	0.641	1395454	3571032	2175578	309.07	2.85
1991	0.626	1458245	3787368	2329123	376.81	2.86
1992	0.532	1148287	3307678	2159391	296.71	2.71
1993	0.672	1501461	3736905	2235444	387.97	3.60
1994	0.684	1673732	4119158	2445426	432.49	3.78
1995	0.712	1744961	4196363	2451402	450.89	4.09
1996	0.749	1982241	4627727	2645486	466.41	4.45
1997	0.732	2058589	4871518	2812929	404.84	4.55
1998	0.815	2372928	5283578	2910650	466.65	5.16
1999	0.757	2344124	5442425	3098301	527.96	4.81
2000	0.785	1953847	4441980	2488133	440.06	4.92
2001	0.860	2075250	4489028	2413778	467.40	5.35
2002	0.875	1759240	3768935	2009695	396.23	5.19
2003	0.992	2135236	4288741	2153505	480.91	5.91
Average	0.739	1795387	4225754	2430367	413.22	4.20

Mine K

Year	Efficiency	Actual Output	Potential Output	Loss in Output	Output/ Capital	Output/ Labor
1989	0.815	3001455	6683583	3682128	313.89	2.12
1990	0.809	3228971	7221798	3992827	363.66	2.28
1991	0.822	3711274	8227911	4516637	388.13	2.77
1992	0.603	2913730	7746573	4832843	304.72	2.40
1993	0.640	3431384	8795232	5363848	358.86	2.70
1994	0.649	3993838	10143198	6149360	417.68	2.76
1995	0.616	4097163	10743183	6646020	399.92	3.06
1996	0.544	3239695	9194409	5954714	431.21	2.85
1997	0.481	1588024	4890993	3302969	581.27	3.11
1998	0.700	1389309	3373812	1984503	508.53	4.31
1999	0.581	1295750	3524405	2228655	474.29	3.68
2000	0.620	1505399	3931996	2426597	551.02	4.02
2001	0.615	1569495	4121057	2551562	459.59	3.90
2002	0.538	1490794	4264147	2773353	345.49	3.42
2003	0.521	1567367	4577419	3010052	363.24	3.36
Average	0.637	2534910	6514705	3979796	417.43	3.12

Mine L

Year	Efficiency	Actual Output	Potential Output	Loss in Output	Output/ Capital	Output/ Labor
1989	0.846	1533445	3346861	1813416	415.46	3.64
1990	0.832	1655782	3645906	1990124	440.37	3.75
1991	0.853	1674708	3637924	1963216	445.40	4.21
1992	0.851	1999565	4349681	2350116	664.75	4.25
1993	0.766	737830	1701409	963579	327.05	4.26
1994	0.792	1780000	4026345	2246345	789.01	4.73
1995	0.732	1501000	3552915	2051915	665.34	4.48
1996	0.762	1713000	3961614	2248614	455.59	4.52
1997	0.743	1925000	4516346	2591346	428.92	4.55
1998	0.855	2390000	5184728	2794728	532.53	5.33
1999	0.827	2516000	5556602	3040602	565.14	5.26
2000	0.758	2420000	5613412	3193412	543.58	4.90
2001	0.789	2634000	5970794	3336794	593.24	5.18
2002	0.752	2549000	5937209	3388209	574.10	4.98
2003	0.727	2547000	6049959	3502959	573.65	4.85
Average	0.792	1971755	4460291	2488536	534.27	4.59

Table A.2: Output Growth Decomposition of Individual Mines

Mine A

Time period	Output growth	Input growth	TFP growth	Change in TE	TP
1989-1990	0.0000	0.0000	0.0000	-0.0085	0.0085
1990-1991	0.3498	0.2869	0.0629	0.0596	0.0033
1991-1992	0.0392	0.1151	-0.0759	-0.0975	0.0216
1992-1993	0.0963	0.0881	0.0082	-0.0136	0.0219
1993-1994	0.0602	0.0386	0.0215	0.0008	0.0207
1994-1995	0.0746	0.1151	-0.0405	-0.0578	0.0172
1995-1996	0.0041	0.0413	-0.0372	-0.0541	0.0169
1996-1997	-0.0125	0.2528	-0.2654	-0.2788	0.0134
1997-1998	0.0700	-0.1806	0.2506	0.2324	0.0183
1998-1999	0.2837	0.0999	0.1838	0.1766	0.0072
1999-2000	-0.0914	0.0234	-0.1148	-0.1209	0.0061
2000-2001	-0.1170	0.1928	-0.3098	-0.3117	0.0018
2001-2002	0.0000	0.0000	0.0000	-0.0040	0.0040
2002-2003	0.0000	0.0000	0.0000	0.0012	-0.0012
Average	0.0541	0.0767	-0.0226	-0.0340	0.0114

Mine B

Time period	Output growth	Input growth	TFP growth	Change in TE	TP
1989-1990	0.1782	0.1064	0.0718	-0.0013	0.0731
1990-1991	-0.3160	-0.2029	-0.1131	-0.1925	0.0793
1991-1992	-0.0396	-0.0102	-0.0295	-0.0877	0.0582
1992-1993	0.1118	0.0988	0.0130	-0.0408	0.0537
1993-1994	-0.0057	-0.0296	0.0239	-0.0307	0.0546
1994-1995	-0.9602	-0.8142	-0.1460	-0.1937	0.0477
1995-1996	0.1297	-0.0267	0.1564	0.1564	0.0000
1996-1997	0.4362	0.3320	0.1042	0.1108	-0.0066
1997-1998	0.1299	0.1579	-0.0280	-0.0314	0.0034
1998-1999	-0.4006	-0.1993	-0.2013	-0.2066	0.0054
1999-2000	0.0000	0.0000	0.0000	0.0084	-0.0084
2000-2001	0.0000	0.0000	0.0000	0.0136	-0.0136
2001-2002	0.0000	0.0000	0.0000	0.0187	-0.0187
2002-2003	0.0000	0.0000	0.0000	0.0239	-0.0239
Average	-0.0526	-0.0420	-0.0106	-0.0323	0.0217

Mine C

Time period	Output growth	Input growth	TFP growth	Change in TE	TP
1989-1990	0.0000	-0.0233	0.0233	-0.0386	0.0620
1990-1991	0.1574	0.0023	0.1551	0.1005	0.0546
1991-1992	0.1239	0.0101	0.1138	0.0699	0.0438
1992-1993	0.2043	0.0257	0.1786	0.1409	0.0377
1993-1994	0.0295	-0.0037	0.0332	-0.0134	0.0466
1994-1995	-0.0370	-0.0674	0.0304	-0.0108	0.0412
1995-1996	0.0886	0.0510	0.0377	0.0054	0.0322
1996-1997	0.1185	0.1264	-0.0079	-0.0392	0.0313
1997-1998	-0.3844	-0.3672	-0.0172	-0.0493	0.0321
1998-1999	0.1398	0.3898	-0.2500	-0.2605	0.0105
1999-2000	0.0387	0.0847	-0.0460	-0.0680	0.0220
2000-2001	-0.1093	-0.2418	0.1324	0.1121	0.0204
2001-2002	0.0570	-0.1408	0.1978	0.1922	0.0055
2002-2003	-0.0950	-0.1458	0.0508	0.0573	-0.0065
Average	0.0237	-0.0214	0.0451	0.0142	0.0310

Mine D

Time period	Output growth	Input growth	TFP growth	Change in TE	TP
1989-1990	0.0000	0.0000	0.0000	-0.0098	0.0098
1990-1991	0.8788	0.3228	0.5560	0.5513	0.0047
1991-1992	0.4604	0.2351	0.2253	0.2113	0.0140
1992-1993	0.1397	0.1340	0.0056	-0.0137	0.0193
1993-1994	0.1047	0.1405	-0.0358	-0.0586	0.0228
1994-1995	-0.0630	-0.0333	-0.0297	-0.0537	0.0241
1995-1996	0.1338	-0.0332	0.1670	0.1496	0.0174
1996-1997	0.2174	0.1886	0.0287	0.0179	0.0108
1997-1998	-0.0308	-0.1931	0.1623	0.1514	0.0109
1998-1999	0.0861	0.3126	-0.2265	-0.2232	-0.0033
1999-2000	0.1999	0.1507	0.0492	0.0436	0.0056
2000-2001	0.1577	0.1264	0.0313	0.0270	0.0044
2001-2002	-0.1369	-0.0735	-0.0633	-0.0682	0.0049
2002-2003	0.0242	0.1767	-0.1525	-0.1490	-0.0035
Average	0.1551	0.1039	0.0513	0.0411	0.0101

Mine E

Time period	Output growth	Input growth	TFP growth	Change in TE	TP
1989-1990	-0.1810	0.1469	-0.3279	-0.3410	0.0131
1990-1991	0.7402	0.5103	0.2299	0.2154	0.0145
1991-1992	0.7285	0.0199	0.7086	0.6733	0.0354
1992-1993	-0.2335	0.1887	-0.4222	-0.4525	0.0304
1993-1994	-0.0932	-0.0761	-0.0171	-0.0529	0.0359
1994-1995	-0.0068	-0.0347	0.0280	0.0033	0.0247
1995-1996	0.1974	0.0992	0.0982	0.0781	0.0201
1996-1997	0.1671	0.4487	-0.2816	-0.2994	0.0178
1997-1998	0.1965	-0.0500	0.2464	0.2111	0.0353
1998-1999	0.1294	0.0427	0.0866	0.0672	0.0194
1999-2000	-0.1020	0.0420	-0.1440	-0.1606	0.0166
2000-2001	-0.3955	-0.4063	0.0108	-0.0028	0.0136
2001-2002	0.0000	0.0000	0.0000	0.0112	-0.0112
2002-2003	0.0000	0.0000	0.0000	0.0164	-0.0164
Average	0.0819	0.0665	0.0154	-0.0024	0.0178

Mine F

Time period	Output growth	Input growth	TFP growth	Change in TE	TP
1989-1990	0.0723	0.0100	0.0623	-0.0426	0.1049
1990-1991	0.1604	0.0845	0.0759	-0.0190	0.0949
1991-1992	0.0600	0.0000	0.0600	-0.0265	0.0865
1992-1993	0.0983	-0.0383	0.1366	0.0553	0.0813
1993-1994	-0.0354	-0.0176	-0.0178	-0.0941	0.0763
1994-1995	0.3340	0.0731	0.2609	0.1883	0.0726
1995-1996	0.1504	0.0611	0.0893	0.0227	0.0666
1996-1997	-0.2718	0.1278	-0.3996	-0.4673	0.0677
1997-1998	0.1032	-0.1221	0.2253	0.1642	0.0611
1998-1999	0.1680	-0.0736	0.2416	0.1935	0.0481
1999-2000	0.1431	0.0634	0.0796	0.0221	0.0575
2000-2001	-0.0702	-0.0282	-0.0420	-0.0984	0.0564
2001-2002	-0.1027	0.0637	-0.1664	-0.2159	0.0495
2002-2003	-0.0509	0.2441	-0.2950	-0.3430	0.0480
Average	0.0542	0.0320	0.0222	-0.0472	0.0694

Mine G

Time period	Output growth	Input growth	TFP growth	Change in TE	TP
1989-1990	0.0815	-0.0566	0.1381	0.0435	0.0946
1990-1991	-0.0196	0.0533	-0.0730	-0.1478	0.0748
1991-1992	-0.0438	0.0484	-0.0922	-0.1676	0.0754
1992-1993	-0.0605	0.0383	-0.0988	-0.1687	0.0699
1993-1994	0.2015	-0.1434	0.3448	0.2764	0.0685
1994-1995	-0.0193	-0.1810	0.1617	0.1128	0.0489
1995-1996	0.1463	-0.0984	0.2447	0.2053	0.0394
1996-1997	0.1842	0.0344	0.1498	0.1131	0.0367
1997-1998	-0.0110	-0.0414	0.0304	-0.0028	0.0332
1998-1999	0.0555	0.0032	0.0523	0.0277	0.0245
1999-2000	-0.1318	0.0848	-0.2165	-0.2375	0.0210
2000-2001	0.1778	-0.0149	0.1927	0.1733	0.0194
2001-2002	0.0211	0.0419	-0.0208	-0.0344	0.0136
2002-2003	-0.0830	-0.0027	-0.0803	-0.0904	0.0101
Average	0.0356	-0.0167	0.0523	0.0073	0.0450

Mine H

Time period	Output growth	Input growth	TFP growth	Change in TE	TP
1989-1990	-0.0133	-0.0262	0.0129	-0.0745	0.0874
1990-1991	0.0001	0.0090	-0.0089	-0.0894	0.0805
1991-1992	0.0884	-0.1692	0.2576	0.1817	0.0759
1992-1993	0.0556	0.0115	0.0441	-0.0195	0.0636
1993-1994	-0.0092	-0.0868	0.0776	0.0186	0.0591
1994-1995	-0.0897	-0.0736	-0.0161	-0.0649	0.0488
1995-1996	-0.0063	-0.0241	0.0178	-0.0189	0.0367
1996-1997	0.1118	0.0231	0.0887	0.0630	0.0256
1997-1998	0.0583	0.0092	0.0491	0.0273	0.0218
1998-1999	0.0888	0.0526	0.0362	0.0190	0.0171
1999-2000	0.0483	-0.0410	0.0893	0.0746	0.0147
2000-2001	-0.2566	-0.1110	-0.1457	-0.1532	0.0075
2001-2002	-0.0225	-0.0946	0.0721	0.0750	-0.0029
2002-2003	-0.0139	0.1062	-0.1202	-0.1079	-0.0123
Average	0.0028	-0.0296	0.0325	-0.0049	0.0374

Mine I

Time period	Output growth	Input growth	TFP growth	Change in TE	TP
1989-1990	0.1143	0.0556	0.0587	-0.0363	0.0950
1990-1991	-0.0121	0.0205	-0.0325	-0.1291	0.0966
1991-1992	0.1037	0.0007	0.1030	0.0092	0.0937
1992-1993	-0.7705	-0.4450	-0.3255	-0.4162	0.0906
1993-1994	0.6558	0.4652	0.1907	0.1405	0.0502
1994-1995	0.1889	0.0454	0.1435	0.0766	0.0669
1995-1996	-0.0255	-0.0465	0.0210	-0.0448	0.0658
1996-1997	0.2481	0.0580	0.1900	0.1416	0.0484
1997-1998	0.0032	-0.0211	0.0244	-0.0225	0.0468
1998-1999	-0.0857	0.0752	-0.1609	-0.2010	0.0400
1999-2000	-0.3168	-0.0141	-0.3027	-0.3426	0.0399
2000-2001	-0.3392	-0.1892	-0.1500	-0.1857	0.0357
2001-2002	-0.1557	-0.6575	0.5018	0.4828	0.0190
2002-2003	0.0000	0.0000	0.0000	0.0218	-0.0218
Average	-0.0280	-0.0466	0.0187	-0.0361	0.0548

Mine J

Time period	Output growth	Input growth	TFP growth	Change in TE	TP
1989-1990	0.0501	-0.0044	0.0545	-0.0116	0.0661
1990-1991	0.0440	0.0077	0.0363	-0.0242	0.0605
1991-1992	-0.2390	-0.1360	-0.1029	-0.1635	0.0605
1992-1993	0.2682	-0.0106	0.2787	0.2338	0.0449
1993-1994	0.1086	0.0508	0.0579	0.0189	0.0390
1994-1995	0.0417	-0.0348	0.0764	0.0393	0.0371
1995-1996	0.1275	0.0463	0.0812	0.0514	0.0298
1996-1997	0.0378	0.0360	0.0018	-0.0236	0.0254
1997-1998	0.1421	0.0164	0.1257	0.1081	0.0176
1998-1999	-0.0122	0.0491	-0.0614	-0.0748	0.0134
1999-2000	-0.1821	-0.2334	0.0512	0.0373	0.0140
2000-2001	0.0603	-0.0278	0.0881	0.0907	-0.0026
2001-2002	-0.1652	-0.1741	0.0089	0.0180	-0.0091
2002-2003	0.1937	0.0855	0.1082	0.1300	-0.0219
Average	0.0340	-0.0235	0.0575	0.0307	0.0268

Mine K

Time period	Output growth	Input growth	TFP growth	Change in TE	TP
1989-1990	0.0731	-0.0302	0.1032	-0.0079	0.1112
1990-1991	0.1392	0.0157	0.1235	0.0160	0.1075
1991-1992	-0.2419	-0.0298	-0.2121	-0.3099	0.0978
1992-1993	0.1635	0.0170	0.1466	0.0594	0.0872
1993-1994	0.1518	0.0520	0.0998	0.0152	0.0846
1994-1995	0.0255	-0.0088	0.0344	-0.0522	0.0865
1995-1996	-0.2348	-0.1855	-0.0493	-0.1251	0.0758
1996-1997	-0.7130	-0.6566	-0.0564	-0.1238	0.0673
1997-1998	-0.1337	-0.5459	0.4123	0.3762	0.0361
1998-1999	-0.0697	0.1111	-0.1808	-0.1859	0.0052
1999-2000	0.1500	0.0801	0.0698	0.0650	0.0049
2000-2001	0.0417	0.0471	-0.0054	-0.0085	0.0031
2001-2002	-0.0514	0.0857	-0.1371	-0.1349	-0.0022
2002-2003	0.0501	0.0891	-0.0390	-0.0318	-0.0072
Average	-0.0464	-0.0685	0.0221	-0.0320	0.0541

Mine L

Time period	Output growth	Input growth	TFP growth	Change in TE	TP
1989-1990	0.0768	0.0319	0.0448	-0.0162	0.0611
1990-1991	0.0114	-0.0718	0.0832	0.0250	0.0582
1991-1992	0.1773	0.1327	0.0446	-0.0026	0.0472
1992-1993	-0.9970	-0.9470	-0.0500	-0.1055	0.0555
1993-1994	0.8807	0.8466	0.0341	0.0343	-0.0002
1994-1995	-0.1705	-0.1285	-0.0420	-0.0800	0.0381
1995-1996	0.1321	0.0651	0.0670	0.0406	0.0263
1996-1997	0.1167	0.1233	-0.0066	-0.0252	0.0186
1997-1998	0.2164	0.0591	0.1572	0.1410	0.0163
1998-1999	0.0514	0.0700	-0.0187	-0.0330	0.0143
1999-2000	-0.0389	0.0362	-0.0751	-0.0880	0.0129
2000-2001	0.0847	0.0343	0.0504	0.0409	0.0096
2001-2002	-0.0328	0.0093	-0.0421	-0.0481	0.0061
2002-2003	-0.0008	0.0320	-0.0328	-0.0341	0.0013
Average	0.0362	0.0209	0.0153	-0.0108	0.0261

TE: Technical Efficiency; TP: Technological Progress;
TFP: Total Factor Productivity