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Abstract

This paper analyses the energy use in the manufacture of cement in India during 1992–2005. Cement manufacturing requires large amounts of various energy inputs. The most common types of energy carriers used are coal, electricity, natural gas and fuel oil. Over the years, the fuel use shift is less, but use of natural gas has decreased and that of electricity has increased. Using panel data, stochastic frontier production function method has been used to evaluate the efficiency of individual firms and industries across the years. The results show a significant decrease in energy as well as carbon intensities because of differences in production techniques.

Keywords:

Cement industry, Energy demand, Firm, Technical efficiency

JEL Code:

Q4, L94, L95, L98

Acknowledgements:

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Abstract

This paper analyses the energy use in the manufacture of cement in India during 1992–2005. Cement manufacturing requires large amounts of various energy inputs. The most common types of energy carriers used are coal, electricity, natural gas and fuel oil. Over the years, the fuel use shift is less, but use of natural gas has decreased and that of electricity has increased. Using panel data, stochastic frontier production function method has been used to evaluate the efficiency of individual firms and industries across the years. The results show a significant decrease in energy as well as carbon intensities because of differences in production techniques.

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1. Introduction

Cement is the most commonly used construction material and hence an important input to economic activity. The energy consumption in the cement industry is about 3% of the world primary energy consumption, or about 8% of total industrial energy consumption (IEA, 2010). The industry also contributes 10% to the total global carbon dioxide emissions. Hence, it is important to increase the efficiency of energy use in cement industry.

Based on the composition and percentage of clinker used, different types of cement—Ordinary Portland Cement (OPC), Portland Pozolona Cement (PPC), Portland Blast Furnace Slag Cement (PBFSC), white cement and specialized cement—are produced for various end-uses. The most common type, accounting for 70%, is OPC, also known as Grey cement, which has 95% clinker and gypsum and other materials constituting the rest. PPC accounts for 18% of the total cement consumption with 80% clinker, 15% Pozolona and 5% gypsum. PBFSC accounts for 10% of the total cement consumption with a composition of 45% clinker, 50% blast furnace slag and 5% gypsum. It is generally used in massive constructions such as dams.

Cement production in India, which began in 1914, with a capacity of 1,000 tons reached 209 mtpa by 2010. This capacity is distributed across 129 large cement plants owned by 54 companies. The cement plants are capital intensive and require a capital investment of over Rs. 3,500 per tonne of cement, which translates into an investment of Rs. 3,500 million for one mtpa plant (UNFCC, 2007). Associated Cement industries, UltraTech Cem Co Ltd., Gujarat Ambuja group and Grasim Cement are the largest cement-producing companies in the country.

India has the third largest cement market in the world with a range of mini to large capacity cement plants with unit capacity per kiln as low as 10 tpd (tons per day) and as high as 7,500 tpd. Nearly 95% of the production is from large plants having capacity of more than 600 tpd. In general, rotary kiln technology is used in large plants and vertical kiln technology in small plants. A cement production plant consists three processes: (i) Raw material process, (ii) Clinker burning process and (iii) Finish grinding process. The raw material and clinker burning processes are further classified as wet and dry processes. These processes are selected with consideration given to properties of raw materials, costs of fuel and conditions of location. In the wet process, plant construction cost is rather low and high-quality products are manufactured easily. On the other hand, the dry process consumes less energy and its running cost is lower. Over the years, the share of wet process is declining owing to high energy use and associated costs. There are significant variations in efficiency (output/input) across firms which lead to wastage of limited resources (energy, raw materials, etc).

The objectives of the present paper are to: (i) find out the pattern of energy use—including fuel type—in the cement manufacturing industry during the last 15 years, (ii) find variations in technical efficiency across firms, (ii) find out the factors that affect technical efficiency, and (iii) design policy prescriptions. To access variations in technical efficiency and the factors affecting it across firms, we use Stochastic Frontier Analysis (STF) method for the period 1992–2005.

2. Methodology of the study

2.1 Literature review

A production function assumes a parametric functional relationship between output and input effort vector X. The Cobb-Douglas (CD) production function has traditionally been used for estimating the return to production process. In recent years, it has been recognized as being rather restrictive (Hanneson, 1983) and the Schaefer form has been extended to several different forms of Constant Elasticity of Substitution, Cobb-Douglas (a special case of the CES form) and the translog are employed. CD and CES are associated with simplicity, straightforward interpretation of parameters of the functions and hence with their direct applicability in policy matters (Varian, 1992). The translog function is more general than the CD and CES, as it allows for varying returns to scale and varying factor elasticity of substitution. It may generally be viewed as a second-order Taylor approximation to an arbitrary production form (Heathfield and Wibe,1987). It covers a wide variety of production functions and hence is being widely employed. While the translog form and the logarithm of CD are both linear, the CES form, on the contrary, is non-linear and cannot be linearised analytically. Estimating functional parameters for the CES includes non-linear fitting techniques which are generally recognized as being complicated and have convergence problems (local extrema, etc.). However, the two-input CES forms may, in certain cases, be approximated by a linear translog form (Kmenta, 1967).

The stochastic frontier production function (SFPF) method was developed by Aigner *et al.* (1977) and Meeusen *et al.* (1977), while evaluating the efficiency of individual firms and industries across time using panel data. The frontier production function assumes the existence of technical inefficiency of different firms involved in production such that specific values of factor inputs and the level of production are less than what would be the case if the firms were technical efficient. This approach has become an important tool for analyzing the of the firm with increasing availability of firm-level input–output data and increasing computation facility, particularly after the availability of high-end computers. The most common approach to estimate SFPF is to specify a deterministic, parametric production function (common to production theory in microeconomics). The stochastic frontier is then defined as the deterministic production function plus a random, symmetric, firm-specific error term. The SFPF model, associated with each firm, has two-part error term out of which the second part, which is a non-negative term, denotes the technical inefficiency. Models for SFPF have been proposed in literature (Kumbhakar 1990, Cornwell *et al.*1990, and Battese and Coelli, 1992) in which the firm effects associated with technical inefficiency are assumed to be time-varying. Non stochastic inefficiency effects (i.e. the inefficiency effects, not depending on firm-specific variables and time of observation) are considered as null hypotheses and get rejected.

Arya (1981) studied technological and productivity changes of 15 cement manufacturing companies. Using data from annual reports of companies for the years 1956–72, the author estimated CD production functions. The trend rates of growth showed a wide variation across the sample and fell in the range of 0.8–6.8% p.a. The capital intensity during the time period increased at an average rate of 2.8% p.a. for the sample. Mehta (1980) estimated CD production function for energy-intensive industries including cement industry for the period 1953-1965. The results show the evidence of capital deepening in the production process but could not conclude any clear trend regarding technical efficiency improvements. Schumacher and Sathaye (1999) investigated the total factor productivity growth in India's cement sector and found that productivity has slightly increased over time. Translog, Solow and Kendrick indices were developed using theoretical and empirical frameworks with special emphasis on energy as a critical factor using a four-factor input approach (K, L, E, M). The results indicate an increase in production (4.8% p.a.) for the period 1983–1993. This is mainly due to the partial decontrol of cement sector in 1982. In the analyses, the values of input and output variables are taken in monetary terms. Saygili (1998) analyzed the Turkish cement industry based on Stochastic frontier analysis and found that predictions of efficiency wage theories appear to be a significant positive link between wages and output and between wages and technical efficiency of the plants.

There are some other issues, related to statistical models, which are worth mentioning. Firstly, the engineering models generally represent the best practice technologies while statistical models are typically based on average ones. Secondly, measures of technical efficiency, based on average practice, have limited use in managing energy. A more useful measure could be the distribution of performances where a company or plant lies and the important question to ask is how close the performance is from the industries' best practices. To achieve this objective, we modify the existing statistical approach and developed industrial energy performances indicators to asses the "best practice" and "efficiency gap". Stochastic frontier regression analysis has been applied by using firm-level data on raw materials, energy use and production values. The variation in efficiency can exist for a number of reasons which include: economics decisions (energy price, utilization rate, etc.) and structural differences (production process, material choice, energy carrier choice, etc.). The statistical models are well suited to account for these differences but no explicit treatment of "best" and "average" practices. The existing methodological options to estimate the efficiency gap include: (i) linear regression which computes the "typical" performance giving exogenous effects and explains variations by finding the best fit line which goes through the mean of the data and any deviation is a "statistical noise" which is assumed to be normally distributed (i.e. positive or negative), and (ii) Stochastic Frontier, which is a modified regression, where the frontier computes the best performance given the same exogenous effects. Linear regression explains the data by finding the best fit line which "envelopes the frontier" of data and then the deviation as "noise". However, this analysis is inconclusive as the deviations may also be inefficient which is assumed to follow a one-sided distribution. So, to analyze production efficiency across firms and over time, stochastic frontier production function model (with translog production function) is adopted in which non-negative technical inefficiency effects are assumed to be a function of firm-specific variables.

2.2 Stochastic frontier production function

For panel data, consider the stochastic frontier production function

$$Y_{it} = \beta_0 + X_{it}\beta + E_{it} \tag{1}$$

$$E_{it} = V_{it} - U_{it} \tag{2}$$

where

Y_{it} denotes the production for *i*-th firm (*I* = 1, 2 …..N) for the *t*-th period (*t* = 1, 2….T).

X_{it} denotes a (1 × K) vector of value of known function of inputs of production and other explanatory variables associated with the *i*-th firm for the *t*-th period

β denotes a (K × 1) vector of unknown parameter to be estimated.

Equations (1) and (2) specify the stochastic frontier production function in term of the original production value was proposed initially by Aigner *et al.* (1977), and Meusen *et al.* (1977). The V_{it} are assumed to be iid $N(0, \sigma_v^2)$ with random error which may be a simple linear or log linear regression model or Translog production function and distributed independent of the U_{it}. The U_{it} are non-negative random variables, associated with technical inefficiency of the production which are assumed to be independently distributed, such that U_{it} is obtained with normal distribution with means μ and variance σ_u^2 and truncation at zero. The subtraction of the truncated random variables U_{it} from other random error V_{it} implies that logarithm of production is smaller than it would otherwise be if technical inefficiency does not exist (see Battese, 1992, for extensive review of concepts and models for frontier production function). The time-varying behavior of the non-negative firm effects, U_{it}, has been defined by equation 3 (Battese and Coelli, 1992). Recently SFP model for panel data have been presented in which time-varying firm effects have been specified. Cornwell *et al.* (1987), in their empirical analysis of twelve years of quarterly data on U.S airline companies, considered a frontier model in which the firm-effect random disturbances are a quadratic function of time in which the coefficients vary over the firms according to the specifications of a multivariate distribution. And parameters of the model were estimated by instrumental-variable methods.

$$U_{it} = \eta_{it} U_i = \{Exp[-\eta(t-T)]\} U_i \quad (3)$$

$$\sigma_s^2 = \sigma_v^2 + \sigma_u^2 \quad (4)$$

$$\gamma = \frac{\sigma_u^2}{\sigma_v^2 + \sigma_u^2}\ , \quad 0 < \gamma < 1 \quad (5)$$

For our stochastic frontier analysis modeling framework, we use the test hypothesis described in Table 1 to attain the best model on available data set.

The density function for U_i, which is defined in the stochastic frontier model (1), could be specified as follows:

$$f_{U_{it}}(u) = \frac{Exp\left[-\frac{1}{2}(u-\mu)^2 / \sigma^2\right]}{(2\Pi)^{1/2}\sigma\left[1-\Phi(-u/\sigma\right]} \quad ,u > 0 \quad (6)$$

where $\Phi(.)$ denotes the distribution function of the standard normal random variable.

2.3 Technical efficiency and TFP

The model uses equations (4) and (5) to estimate the Technical Efficiency (TE) of the *i*-th firm, denoted by TE_i

$$TE_i = \frac{E\left[Y_{it}^* / U_i \ , X_{it}, t = 1,2,3......\right]}{E\left[Y_{it}^* / U_i = 0, X_{it}, t = 1,2,3,....\right]} \quad (7)$$

If production function defined in equations (1) and (2) defined directly in terms of the original units of production, then Technical efficiency (TE) of the *i*-th firm will be

$$TE_i = \frac{\left[X_i \bar{\beta} - U_i\right]}{\left[X_i \bar{\beta}\right]} \quad (8)$$

where $\bar{X}_i$ is the mean of the input level for the *i*-th firm.

If equations (1) and (2) are defined in logarithm of production, then the production for the *i*-th firm in the *t*-th period is $Exp(Y_{it})$. Then, the Technical efficiency of the *i*-th firm (ratio of the production of the *i*-th firm in any given period *t*) is given by equation (9). It should be noted that the TE in the equation does not depend on the level of the factor inputs for the given firm.

$$TE_i = \frac{Exp\left[X_{it}\beta + V_{it} - U_i\right]}{Exp\left[X_{it}\beta + V_{it}\right]} = Exp(U_i) \quad (9)$$

The distribution of the non-negative firm-effect random variables is suggested by Stevenson (1980), which is a generalization of the truncated distribution in which μ is the mean. Pitt and Lee (1981) and Schmidt and Sickles (1984) considered the special case of this model in which the firm effects had half-normal distribution. Pitt and Lee (1981) and Schmidt (1984) have suggested that firms may discover, after a period of time, the extent of their inefficiency and adjust their input values accordingly. Schmidt (1986) had pointed that unchanged inefficiency over time is particularly not an attractive proposition, but Schmidt had made one more point that to search for a model where one can find the inefficiency to change over time is an important research direction. The time-invariant model for the non-negative firm effects was considered by Battese and Coelli (1988) for the case in which the firm effects were non-negative truncations of the $N(\mu,\sigma^2)$ distribution. Battese *et al.* (1995) considered the case in which the numbers of time-series observations of different firms were not equal. The authors formulated the computer code FRONTIER for estimation of the maximum-likelihood and predictions for technical inefficiencies of the firms of interest. The density function for U_{it} is defined by equation (10) and used for inefficiency factor modeling for firm level data.

$$U_{it} = Z_{it}\delta + W_{it} \quad (10)$$

where

Z_{it} = (M × 1) vector of explanatory variables associated with technical inefficiency of production of firm over time

δ = (M × 1) vector of unknown coefficients

W_{it} = A random variable defined by the truncation of the normal distribution with zero means and variance σ^2, such that the point of truncation is $Z_{it}\delta$, i.e. $W_{it} >= -Z_{it}\delta$.

The assumption is that U_{it} is a non-negative truncation of the $N(Z_{it}\delta,\sigma^2)$ distribution. The inefficiency of frontier production function (8) and (9) differs from that of Reifschneider and Stevenson (1991) in the sense that the *W*-random variables are neither identically distributed nor are they required to be non-negative. This means that $Z_{it}\delta$ is normally distributed, which is truncated at zero and distribution of U_{it} is not required to be positive for each observation as in

Reifschneider and Stevenson (1991). If the frontier production function (8) and (9) is defined for the log value of production, then the production for the *i*-th firm in the *t*-th period is exp(Y_{it}). The estimation and selection process have been done to find out a better model among those described above. The proposed process of estimation is as follows:

Model 1: Involves all parameters being estimated (having the times-varying structure)

Model 2: Assumes that $\mu = 0$ (U_i have half-normal distribution)

Model 3: Assumes that $\eta = 0$ (having time-invariant model)

Model 4: Assumes that $\mu = \eta = 0$ (having time-invariant model in which the U_i have half-normal distribution) and

Model 5: Assumes that $\gamma = \mu = \eta = 0$ (average response function in which firms are assumed to be fully technically efficient and the firm effects are absent from the model).

Six tests have been identified. Hypotheses are based on the above five models for selection process. Tests of hypothesis involving the parameters of distribution of the U_{it}-random variables (firm effects) are obtained by using generalized likelihood-ratio test statistics. The test hypotheses for different distributional assumptions and relevant statistics are presented here. The test hypotheses values are estimated, based on the selected final model (acceptance and rejection hypothesis).

Test 1: Test Hypothesis between Models 1 and 5

Test 2: Test Hypothesis between Models 1 and 4

Test 3: Test Hypothesis between Models 1 and 2

Test 4: Test Hypothesis between Models 1 and 3

Test 5: Test Hypothesis between Tests 1 and 2

Test 6: Hypothesis between Tests 1 and 2

Finally, we select a model based on all above tests hypotheses. Then the estimated parameters and their policy implications on improvement in technical efficiency of the cement firm are analyzed. The technical efficiency value over time at the firm level can be considered as a factor affecting energy intensity across firms. The firms that are selected and their code are given in Appendix 1.

3. Energy consumption in cement industry

3.1Capacity utilization

Cement industry uses coal, natural gas and petroleum products to generate thermal energy for clinker production. The capacity utilization has a significant impact on the productivity and efficiency of any industry and cement industry is not an exception. During 1992–2005, the total cement production increased by 209%, from 38 to 116 million tons, while the energy consumption increased by 71.7%, from 275 to 471.4 PJ. The value addition by the cement industry has increased from Rs 61 to 110 billion at a CAGR of 4.64%. During the same period, the capacity utilization of cement production has increased from 86.0 to 93.4% (Figure 1).

3.2 Overall energy intensity

The energy intensity is defined as the energy consumption per ton of cement production. It depends on the type of fuel and its shares in total consumption. Coal is a very important input in cement production and is mainly used in kiln for production of heat (thermal energy) which is used for clinker production. During 1992–2005, the choice of fuels has changed significantly. There has been a general shift towards electricity and petroleum products and alternative wastes such as liquid and solid hazardous wastes. During the same period, the share of coal and gas consumption has decreased from 88 to 83% and 2 to 1%, respectively, whereas the share of electricity and petroleum products increased from 7 to 11% and 2 to 5%, respectively.

3.3 Specific energy intensity

The average energy consumption for the production of one ton of cement is about 3.3GJ that corresponds to 120 kg of coal with an approximate calorific value of 27.5 MJ/kg. The use of waste such as Tire Derived fuels (TDF) is increasing in cement production. More cement kilns are beginning to use shredded tires in kiln and electric arc furnaces. In addition to energy recovery, there is also a corresponding saving of CO_2 emissions released into the atmosphere as waste replaces fossil fuels known for high CO_2 emission (Mitra, 2004). Both municipal and industrial wastes are used as energy resource and the quantity and quality of waste depends on parameters such as: heating value, humidity content, toxicity, etc. The specific energy intensities across firms are shown in Table 3.

In cement industry, the market leader is not always the most energy-efficient one. For example, Grasim Industries Limited and Associated Cement Company Limited together account for 57% of the market share but they are not the leaders in energy efficient processes. The privately owned India Cements Limited is another example as it is the fourth largest cement manufacturer in India, but occupies a lower rank in terms of energy efficiency. Gurarat Ambuja Cements have improved efficiency from 0.55 to 0.92 percent between 1994-2005) During 1992–2006, the average thermal energy intensity of the firms decreased from 1614 to 1088 Kcal/kg. However, there is a large gap between the most efficient firm (560 Kcal/kg) and inefficient one (2380 Kcal/kg). Similarly, the average electrical energy use decreased from 127 to 93 kWh per ton, but the electrical energy intensity across firms varies from 71 to 180 KWh/ton. This shows that some of the firms, particularly the old ones are not efficient and there is a scope for substantial reduction in energy consumption through technology improvisation.

3.4 CO_2 emission intensity

Air emissions are determined both by the type of fuel burned as well as the types of equipment which burn the fuels. Also, pollution is dependent on the kinds of abatement measures employed by the manufacturers. In India, data on emissions is somewhat limited and is often based on emission factors rather than direct measurement. Cement manufacturing, by its very nature, leads to CO_2 (greenhouse gas) emissions, both because CO_2 is released in the process of turning limestone into clinker, as well as in the combustion of fuels. Table 3 shows CO_2 emissions resulting from fuel combustion. As the results show, the overall energy intensity decreased by 44% from 7.24 to 4.05 PJ/ton and the carbon intensity by 41.1% from 905 to 530.6 Kg CO_2/tonne in the same period.

4. Stochastic frontier modeling and technical efficiency analysis

In general, cement firms in India are less efficient than those in the western world. Hence, it is imperative to examine their technical/production efficiency levels in order to identify the factors that contribute to inefficiency. This exercise will help to design policies for increasing the efficiency levels. For this, Translog stochastic frontier production function is used to examine the level and sources of technical inefficiency.

In cement production, many raw materials are used as factors of production and classified into energy and non-energy categories. The energy raw materials include, coal, electricity, gas, firewood, biogas, petroleum products, etc. (in MJ units) and non-energy materials are limestone, gypsum, clay, slag, etc. which are considered in physical terms.

Energy accounts for 30–60% of the total cost of cement production out of which coal has maximum share. Significant amount of energy in the cement industry goes to clinker production and other raw materials which are required to produce clinker. The substitution of clinker with slag reduces the amount of energy and other raw materials, which means that the production efficiency of the firm increases. Age is also an important factor since there is a significant impact of learning by doing process on the production efficiency of the firm. The summary statistics for these variables used in model are presented in transformed form, i.e., in logarithmic form (Table 4).

4.1 Stochastic frontier analysis (STF) modeling and variable selection

A stochastic frontier production function with Translog form (three energy carriers as inputs and cement production as dependent variable) is formulated below. The nomenclature makes the terms self-explanatory.

$$
\begin{aligned}
Ln(Output_{it}) = {} & \beta_0 + \beta_1 Ln(MJCoal_{it}) + \beta_2 Ln(MJElect._{it}) + \beta_3 n(MJPetro_{it}) + \beta_4 Ln(Limestone_{it}) \\
& \beta_5 Ln(Gypsum_{it}) + \beta_6 Ln(Slag_{it}) + \beta_7 (Ln(MJCoal_{it}))^2 + \beta_8 (Ln(MJElect_{it}))^2 + \\
& \beta_9 (Ln(MJPetro_{it}))^2 + \beta_{10} (Ln(Limestone_{it}))^2 + \beta_{11} (Ln(Gypsum_{it}))^2 + \\
& \beta_{12}[Ln(MJCoal_{it}) * Ln(Limestone_{it})] + \beta_{13}[Ln(MJCoal_{it}) * Ln(Gypsum_{it})] + \\
& \beta_{14}[Ln(MJCoal_{it}) * Ln(Slag._{it})] + \beta_{15}[Ln(MJElect._{it}) * Ln(Limestone_{it})] + \\
& \beta_{16}[Ln(MJElect._{it}) * Ln(Gypsum_{it})] + \beta_{17}[Ln(MJElect._{it}) * Ln(Slag_{it})] + \\
& \beta_{18}[Ln(MJPetro._{it}) * Ln(Limestone_{it})] + \quad \beta_{19}[Ln(MJPetro._{it}) * Ln(Gypsum_{it})] + \\
& \beta_{20}[Ln(MJPetro._{it}) * Ln(Slag_{it})] + \beta_{21}[Ln(Limestone_{it}) * Ln(Gypsum_{it})] + \\
& \beta_{22}[Ln(Limestone_{it}) * Ln(Slag_{it})] + \beta_{23}[Ln(Gypsum_{it}) * Ln(Slag_{it})] + V_{it} - U_{it}
\end{aligned}
\tag{11}
$$

The technical inefficiency effects are defined as

$$U_{it} = \delta_0 + \delta_1 * Ln(Capacity\ utilizatio\,n_{it}) + \delta_2 * Ln(Nor.Inv_{it}) + \delta_3 * Ln(Nor.Saw_{it})$$
$$+ \delta_4 * Ln(Nor\_MJCoal_{it}) + \delta_5 * Ln(Nor\_MJElect\_N._{it})$$
$$+ \delta_6 * Ln(Nor\_MJPetro.\_N_{it}) + \delta_7 (Slag_{it}) + \delta_8 * Ln(year_{it}) + W_{it} \quad (12)$$

where, Nor_ is used for normalization of variables with cement output

4.2 Data sources

The analysis uses unbalanced panel data for 31 firms for the period 1994–2005. The main sources of data (both for input and output in actual units) are from CMIE Prowess data base. The analysis is at the firm level and hence we excluded the type of production process from the list of variables. We have considered major inputs like coal, electricity, petroleum products, limestone, gypsum and slag. The energy consumed by cement industry is aggregated at three levels─coal, electricity and petroleum products.

- Coal (MJ)─aggregate of bagasse, fire-wood, coke, coal and lignite.
- Electricity (MJ)─Electricity purchased
- Petroleum products─aggregate of fuel oil, furnace oil, high-speed diesel, light diesel oil, low sulphur heavy stock and petroleum coke.

Different units of fuel (Kg, Kcal, and KWh) are converted into Mega joules (conversion table given in appendix 2).

4.3 Empirical result for technical efficiency analysis

The Stochastic frontier model employed here gives estimates for beta parameters (with other additional parameters with its distribution V_{it} and U_{it} as random variables) and the same is estimated by Maximum-likelihood estimation method. Model 1 corresponds to equation (11) in which the firm effect U_{it} variables (defined with η being an unknown parameter in equation 3) are non-negative truncations of the $N(\mu, \sigma^2)$ distribution.

Model 1: Involves all parameters being estimated (having the time-varying structure)

Model 2: Special case of Model 1 in which the U_i s have half-normal distribution (i.e., μ is assumed to be zero). Assume that $\mu = 0$ (U_i have half normal distribution)

Model 3: Time-invariant model considered by Battese *et al.* (1995) with the assumption of $\eta = 0$

Model 4: This model assumes $\mu = \eta = 0$ (having time-invariant model in which the U_i s have half normal distribution)

Model 5: Here the assumption is $\gamma = \mu = \eta = 0$ (average response function in which firms are assumed to be fully technically efficient and the firm effects are absent).

The statistics related to four parameters associated with the distributions of V_{it} and U_{it} random variables along with t-ratios are presented in Table 5.

The hypothesis tests involving the parameters of distribution of U_{it}-random variables (firm effects) are obtained by using generalized likelihood-ratio test statistics. For the five models we consider six test hypotheses with different distributional assumptions and relevant statistics (Table 6). Given the specifications of stochastic frontier with time-varying firm effects (Model 1), it is evident that the traditional average production function is not an adequate representation of data because the result of Test1 (H_0: $\gamma = \mu = \eta = 0$ rejected). Further, the hypothesis that time-invariants model for firm effects apply is also rejected for Test 2 (H_0: $\mu = \eta = 0$ and η =0 would be rejected). However, the hypothesis that the half-normal distribution is an adequate representation for the distribution of firm effects is not rejected. The half-normal distribution is assumed to be appropriate for defining the distribution of firm effects, and the hypothesis that the yearly firm effects are time-invariant is also rejected.

Given specifications of the stochastic frontier production functions with equation (11) and inputs dependents; technical inefficiency equation (12) is considered here. The parameter estimation results are shown in Tables 7 and 8. The value found for γ is significantly different from zero which shows that there exists a high level of technical inefficiency. The signs of the coefficients of the stochastic frontier are as expected, with the exception of limestone and electricity consumption variables which are negative. The estimate for electricity consumption is insignificant. The elasticity for limestone is negative and significant which might be due to the fact that its usage is high during the time of low production. The positive coefficients for coal, petroleum products, gypsum and slag are in line with expectations.

All the coefficients are found to be significant at 95 percentage confidence level except for the coefficient corresponding to variable the “age of the firm”. The time variable is significant with negative sign which means that the technical inefficiency of cement industry is decreasing over the years. The negative relationships between age, capacity utilization and investment with that of inefficiency suggest that the older the firm, the higher is the utilization and thereby the high investment in plant, machinery, and new technologies. This results in high technical efficiency. Also, as expected, slag and coal use have significant negative relationship with firm technical inefficiency. The higher the use of slag the higher is the efficiency of the firm.

The use of petroleum products and electricity use is positively related to technical inefficiency. This can be explained as follows. The proportion of coal-based thermal energy use is higher than that of electrical and petro-based energy; hence, an increase in input factor which has a minor role will not lead to an increase in output in the same proportion. The salary and wages per ton of output have positive relationship with the technical inefficiency of the firm, which means that they have negative impact on the firm’s technical efficiency. Based on the specifications of Model 2 (involving half-normal distribution), the technical efficiencies of the individual cement firms are estimated for each year of the study period (1994–2005) using the predictor (Table 9).

The firm’s technical efficiency varies with time. The results show that each firm, based on its ability to use the raw materials in an optimal way, has a different efficiency level which is changing over time. During 1994–2005, the average value of technical efficiency of cement industry has increased from 0.69 to 0.73 with little change in upper and lower values. However, the analysis confirms that, within the industry, there is a greater existence of heterogeneity among the firms. The technical efficiencies have been classified into three brands—low (0.0–0.5), medium (0.5–0.8) and high (0.8–1.0). Figure 2 shows the percentage of firms belonging to different technical efficiency bands. The results indicate that, at the higher end of efficiency level, there is a higher fluctuation over time.

5. Conclusions

This paper has factorized technical efficiency of production and energy intensity in cement industry during 1994–2005. The use of time-varying model in unbalanced panel data shows that there is an increment in average technical efficiency indicator by 7.8%. Firm-wise, technical efficiency turns out to be not time-invariant. The analysis confirms the existence of heterogeneity across firms. Factors that affect technical efficiency are the age of the firm, capacity utilization, salary and wages, investment, slag, as well specific energy consumption. The increase in the use of slag and coal increases the technical efficiency of the firm. Capacity utilization is a significant variable that increases technical efficiency. This means that firms which do not utilize their capacity fully are likely to lag in technical efficiency compared to those with higher capacity utilization. Clinker production per ton of cement has positive but insignificant relationship with energy intensity. To attain higher energy efficiency, firms should increase the use of input as slag per unit of cement production and the capacity of utilization of firm. Higher salary and wage bill are indicative of lesser automation; and hence salary and wages show positive and significant relationship with energy intensity. The results also show that energy intensity is negatively correlated to energy price (mainly for coal and electricity). To encourage efficient utilisation, the Government should deregulate the price of coal and electricity and should give incentives to firms to invest in new technologies.

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Table 1: Technical analysis of the SFP

Test Hypothesis	Hypothesis Description	Result
If η = 0	TIE of the firm over time constant	Firms do not improve their Technical Efficiency
If η > 0	Non-negative firm effect for the *i*-th firm declines exponentially and gets minimum value at the last period T of the panel	Firms increase in their Technical Efficiency over time
If γ = 0	The U_{it} non-negative random variables absent from the model	Model becomes Traditional response function
H0: γ = η = μ = 0	Test whether the traditional response function is an adequate representation given the specification of the stochastic frontier production function involved	If accepted, Traditional model is sufficient
H0: μ = 0	The firm effects associated with the last period of observation in the panel would have Truncated normal distribution. Testing the SFP has time-invariant inefficiencies of production.	

Table 2: Specific energy consumption and energy intensity in cement industries

	Energy Consumption (PJ)					Production (mt)	Intensity (GJ/Ton)				
Year	Coal	Electricity	Gas	Petro. products	Total	Cement	Coal	Electricity	Gas	Petro. products	Total
1992	242.1(88)	20.5(7)	7.5(3)	4.6(2)	274.6	37.9	6.4	0.5	0.2	0.1	7.2
1993	195.4(87)	18.4(8)	5.8(3)	3.8(2)	223.4	34.4	5.7	0.5	0.2	0.1	6.5
1994	194.1(87)	22(10)	4.9(2)	3.2(1)	224.3	40.4	4.8	0.6	0.1	0.1	5.6
1995	201.9(86)	24(10)	6.3(3)	3.8(2)	236.1	42.5	4.8	0.6	0.2	0.1	5.6
1996	214(85)	23.9(10)	6.2(2)	6.2(2)	250.3	46.8	4.6	0.5	0.1	0.1	5.3
1997	229.2(85)	26.7(10)	6.8(3)	7.4(3)	270.1	50.7	4.5	0.5	0.1	0.2	5.3
1998	249.8(85)	28.6(10)	4.4(1)	10.7(4)	293.6	57.4	4.4	0.5	0.1	0.2	5.1
1999	255.2(84)	32.2(11)	3.7(1)	12.5(4)	303.5	66.9	3.8	0.5	0.1	0.2	4.5
2000	260.4(83)	35.1(11)	3.6(1)	16(5)	315.1	75	3.5	0.5	0.1	0.2	4.2
2001	252.8(84)	30.2(10)	3.5(1)	15.3(5)	301.8	72.5	3.5	0.4	0.1	0.2	4.2
2002	279.1(83)	37.2(11)	3.2(1)	15.8(5)	335.3	82.7	3.4	0.5	0	0.2	4.1
2003	291.2(82)	44.2(12)	3.6(1)	17.8(5)	356.8	89.5	3.3	0.5	0.0	0.2	4.0
2004	354.4(82)	52.3(12)	4.1(1)	20.4(5)	431.3	108.4	3.3	0.5	0.0	0.2	4.0
2005	392.1(83)	52.2(11)	4.5(1)	22.3(5)	471.4	116.9	3.4	0.4	0.0	0.2	4.0

Note: Figures in parentheses are percentage shares of fuels.

Table 3: Specific (thermal and electrical) intensities across firms

Year	Type of intensity			
	Thermal (Kcal/kg)		Electrical (KWh/ton)	
	Average	Range	Average	Range
1992	1614	560–2940	127	97–201
1993	1555	670–2310	125	95–207
1994	1374	710–2380	119	56–199
1995	1443	713–2870	116	49.3–200
1996	1408	728–2450	116	89.4–202
1997	1419	742–2800	119	88–220
1998	1258	490–2310	113	83–213
1999	1266	490–2380	103	75.2–203
2000	1170	630–2100	103	75.1–202
2001	1153	490–2100	102	76.3–211
2002	1163	700–2100	114	77.5–244
2003	1191	700–2450	112	73.6–223
2004	1112	630–2380	114	71–221
2005	1108	630–2240	113	71.9–253
2006	1088	560–2380	93	71.27–179

Table 4: Specific CO_2 emission and CO_2 emission intensity over years

Year	Cement production (MT)	Emissions (Million tCO_2)					Intensity ($KgCO_2$/Tonne of cement)				
		Coal	Elect	Gas	Petro	Total	Coal	Elect	Gas	Petro. products	Total
1992	37.9	26.9	6.5	0.5	0.4	34.3	709.8	171.5	13.2	10.6	905.0
1993	34.4	21.7	5.8	0.4	0.3	28.2	630.8	168.6	11.6	8.7	819.8
1994	40.4	21.6	7.0	0.3	0.3	29.2	534.7	173.3	7.4	7.4	722.8
1995	42.5	22.4	7.6	0.4	0.3	30.7	527.1	178.8	9.4	7.1	722.4
1996	46.8	23.8	7.6	0.4	0.5	32.3	508.5	162.4	8.5	10.7	690.2
1997	50.7	25.5	8.4	0.5	0.6	35.0	503.0	165.7	9.9	11.8	690.3
1998	57.4	27.7	9.0	0.3	0.8	37.8	482.6	156.8	5.2	13.9	658.5
1999	66.9	28.3	10.2	0.3	1.0	39.8	423.0	152.5	4.5	14.9	594.9
2000	75.0	28.9	11.1	0.2	1.2	41.4	385.3	148.0	2.7	16.0	552.0
2001	72.5	28.1	9.5	0.2	1.2	39.0	387.6	131.0	2.8	16.6	537.9
2002	82.7	31.0	11.7	0.2	1.2	44.1	374.8	141.5	2.4	14.5	533.3
2003	89.5	32.3	14.0	0.2	1.4	47.9	361.2	156.2	2.8	15.4	535.5
2004	108.4	39.3	16.5	0.3	1.6	57.7	362.8	152.5	2.6	14.5	532.5
2005	116.9	43.5	16.5	0.3	1.7	62.0	372.2	141.1	2.7	14.7	530.6

Table 5: Summary statistics for input and output variables in cement industry

Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Variables	**Average**											
Output	13.1	13.3	13.4	13.3	13.5	13.6	13.6	13.4	13.6	13.5	13.7	13.7
Coal	21.6	21.7	21.8	21.8	21.8	21.8	21.8	21.6	21.7	21.6	21.7	21.7
Electricity	18.4	18.5	18.5	18.4	17.9	17.5	17.6	17	16.9	16.8	16.6	16.3
Petro product	7.5	7.8	8.1	9	9.8	10.2	10.9	10.5	11	10.5	11.8	12.2
Limestone	11.8	13.6	13.7	13.3	13.5	13.5	13.4	13.5	13.9	12.2	13.4	13.4
Gypsum	8.6	9.9	10	9.9	10.1	10.2	10.1	10	9.8	9	9.9	9.9
Slag	2.1	2.7	2.7	2.1	2.9	3.6	3.6	3.8	4.1	3.1	4.1	4.2
Capacity of utilization	86.7	87	87.9	88.1	88.7	89.4	90.2	92.1	91.6	92.2	93.0	93.7
Investment	143.6	126.9	81	106.1	122.1	119.3	153.6	157.4	124	112.5	132.0	133.4
Salary and Wage	152.3	126.2	126.5	123.5	131.7	135.6	113.3	167.3	107.3	138.6	129.6	129.1
	Standard deviation											
Output	1.2	1.1	1.1	1.2	1.1	1.2	1.3	1.5	1.3	1.5	1.5	1.5
Coal	1.2	1	0.9	1	0.9	1	1.1	1.4	1.2	1.5	1.4	1.4
Electricity	3.7	3.8	3.7	3.8	5	5.1	5	5.9	6.1	6.5	6.7	7.1
Petro product	9.2	9.3	9.5	9.6	9.5	9.5	9.5	9.5	9.8	9.6	9.7	9.8
Limestone	4.3	1.7	1.6	1.9	1.7	1.8	1.9	1.7	1.8	3.2	1.9	1.8
Gypsum	3.3	1.4	1.4	1.5	1.4	1.4	1.6	1.7	2.5	3.2	2.2	2.3
Slag	4.2	4.9	5.1	4.6	5.1	5.2	5.3	5.6	5.7	5	5.7	5.8
Capacity of utilization	30.7	29.9	26.2	26	26.7	27.9	26.7	34.5	31.5	40.9	35.0	35.9
Investment	313.2	196.7	120.1	151.9	220.6	253.3	314.7	297	248.9	210.6	261.0	266.1
Salary and Wage	182.7	110.3	104.3	74.3	96.5	102.2	66.7	316.8	58	198.5	158.4	163.4

Table 6: Maximum-likelihood estimation for distribution parameter

Parameter	Model 1 (all parameters estimated)	Model 2 (μ =0)	Model 3 (η =0)	Model 4 ($\mu = \eta$ =0)	Model 5 ($\gamma = \mu = \eta$ =0)
$\sigma_s^2 = \sigma_v^2 + \sigma_u^2$	0.08 (4.4)	0.24 (2.1)	0.12 (7.0)	0.26 (3.0)	0.06
γ	0.67 (8.5)	0.89(14.8)	0.76 (16.)	0.88 (22.)	0
μ	0.46 (4.6)	0	0.61 (5.4)	0	0
η	0.03 (2.9)	0.03 (3.6)	0	0	0
Log likelihood	66.7	66.3	53.4	50.6	-9.9
LR test	153.1	152.14	126.5	121.0	
No of restriction	3	2	2	1	1
Efficiency model	30.74				

Table 7: Tests of hypothesis for parameters for distribution of the firm effects U_{it}

Model	Between	Null Hypothesis	$\chi^2 - Sta$	$\chi_{0.95}{}^2 - tabl$	Decision (H_0)
Test 1	Models 1 and 5	$\gamma = \mu = \eta = 0$	153.14	7.81	Rejected
Test 2	Models 1 and 4	$\mu = \eta = 0$	32.15	5.99	Rejected
Test 3	Models 1 and 2	$\mu = 0$	0.61	3.84	Accepted
Test 4	Models 1 and 3	$\eta = 0$	26.61	3.84	Rejected
Test 5: $\mu = 0$	Tests 1 and 2	$\gamma = \eta = 0$	152.53	5.99	Rejected
Test 6: $\mu = 0$	Tests 2 and 4	$\eta = 0$	31.55	3.84	Rejected

Table 8: Parameter estimates for stochastic frontier production function

Variable (Ln)	Estimate	t-ratio	Variable (Ln)	Estimate	t-ratio
Constant	1.1735	0.96	MJ_Coal* Limestone	0.0856	4.04
MJ_Coal	0.5483	2.21	MJ_Coal*Gypsum	-0.0745	-3.03
MJ_Petro.Prod.	0.4028	1.26	MJ_Coal*Slag	-0.0159	-1.95
MJ_Elect	-0.0109	-0.12	MJ_Elect.*Limestone	-0.0079	-2.01
Limestone	-2.011	-4.75	MJ_Elect.* Slag	-0.007	-2.83
Gypsum	1.7435	3.57	Limestone*Gypsum	-0.0394	-3.85
Slag	0.2922	1.69	Limestone*Slag	0.0289	4.68
Coal $(MJ)^2$	-0.0148	-1.62	sigma-squared	0.0555	7.65
Elect. $(MJ)^2$	0.0084	4.06	Gamma	0.373	2.79
$Limestone^2$	0.0251	4.72			
$Gypsum^2$	0.0365	6.18			

Table 8: Parameter estimates of technical inefficiency model

Estimates for Technical Inefficiency effects					
Variable	Estimate	t-ratio	Variable	Estimate	t-ratio
Constant	4.9978	4.57	Age	-0.044	-1.49
Capacity Utilization	-0.006	-3.38	Ln(Slag)	-0.342	-2.651
Nor_Investment	-0.0004	-3.93	Year	-0.08	-7.004
Nor_Salary and Wage	0.0004	2.03	Sigma-squared	0.0555	7.65
Ln(Nor_MJ_Coal)	-0.4361	-6.41	Gamma	0.373	2.79
Ln(Nor_MJ_Elect)	0.0677	2.24	LLK	30.748	
Ln(Nor_MJ_Petro)	0.1725	3.17	LR test of the one-sided error	81.3051	

Table 9: Summary of predicted TE cement firm for the period 1994–2005

Firm Code	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
1	.	0.98	0.98	.	0.96	0.96	0.97	0.97	0.98	0.82	0.83	0.81
2	0.66	0.94	0.52	0.89	0.89	0.83	0.85	0.53	0.52	0.86	0.84	0.85
3	0.98	0.95	0.91	0.91	0.90	0.87	0.87	0.89	0.92	0.97	0.92	
4	0.97	0.97	0.97	.	0.93	0.93	.	.	.	.		
5	0.53	0.54	0.54	0.54	0.52	.	0.54	0.58	0.57	0.60	0.53	0.53
6	0.36	0.35	0.35	0.36	0.38	0.37	0.38	0.41	0.44	0.49	0.46	0.47
7	0.65	0.69	0.70	0.67	0.69	0.68	0.73	0.75	0.76	0.98	0.86	0.88
8	0.55	0.53	0.56	0.58	0.62	0.71	0.82	0.92	0.92	.	0.95	0.92
9	0.48	0.49	0.59	0.61	0.60	0.64	0.68	0.59	0.61	0.66	0.69	0.70
10	0.57	0.58	0.59	0.58	0.62	0.69	0.62	0.16	0.46	0.20	0.30	0.27
11	0.58	0.63	0.60	0.63	0.64	0.79	0.82	0.86	0.84	0.95	0.93	0.91
12	0.39	0.40	0.38	0.39	0.43	0.43	0.45	0.44	0.47	.	0.47	0.48
13	0.74	0.82	0.91	0.92	0.95	0.96	0.97	0.96	0.54	0.59	0.74	0.72
14	0.65	.	0.66	0.65	0.42	0.45	0.45	0.40	.	.	0.65	.
15	0.97	0.97	0.97	.	0.97	0.97	0.96	0.97	0.97	0.95	0.97	0.97
16	0.87	0.89	0.85	0.88	0.92	0.98	.	0.93	0.93	.	0.97	0.98
17	0.50	0.31	0.29	0.48	0.50	0.51	0.90	0.74	0.78	0.89	0.88	0.77
18	0.77	0.90	0.91	0.92	0.91	0.90	0.93	0.92	0.95	0.98	0.95	0.94
19	0.94	0.72	0.69	0.65	0.59	0.64	0.73	0.63	0.66	0.66	0.59	0.57
20	0.71	0.72	0.72	0.77	0.76	.	0.78	0.82	0.76	0.81	0.78	0.80
21	0.34	0.33	0.37	0.37	0.92	0.93	0.96	0.51	0.42	0.46	0.70	0.73
22	0.98	0.98	0.96	0.97	0.96	0.95	0.96	0.97	0.96	0.97	0.96	0.96
23	.	.	.	.	0.90	0.95	0.96	0.78	0.80	0.85	.	.
24	0.89	0.91	0.90	0.93	0.93	0.99	0.98	0.98	0.98	.	0.95	0.95
25	0.97	0.97	0.98	0.97	0.98	0.97	0.97	0.97	0.97	0.97	0.97	0.97
26	0.42	0.43	0.40	0.41	0.41	0.41	0.40	0.40	0.39	0.40	0.39	0.39
27	0.96	0.91	0.88	0.87	0.93	0.93	0.94	0.93	.	0.95	0.93	0.93
28	0.96	0.96	0.97	0.96	0.96	0.98	0.46	0.68	0.73	0.70	0.61	0.56
29	.	.	0.84	0.90	0.92	0.91	0.91	0.90	0.84	0.87	.	.
30	0.49	0.51	0.44	0.47	.	0.38	0.44	0.52	0.64	0.68	0.45	0.43
31	0.51	0.53	0.55	0.54	0.56	0.58	0.54	0.52	0.51	0.35	0.46	0.45
Mean	0.69	0.71	0.70	0.70	0.76	0.77	0.76	0.72	0.73	0.74	0.74	0.73
S.D	0.22	0.24	0.23	0.21	0.21	0.22	0.21	0.23	0.20	0.23	0.21	0.22
Minimum	0.34	0.31	0.30	0.36	0.38	0.37	0.38	0.16	0.39	0.20	0.30	0.27
Max	0.98	0.98	0.98	0.97	0.98	0.99	0.98	0.98	0.98	0.98	0.97	0.98
No of firm	28	28	30	27	30	29	29	30	28	25	28	26

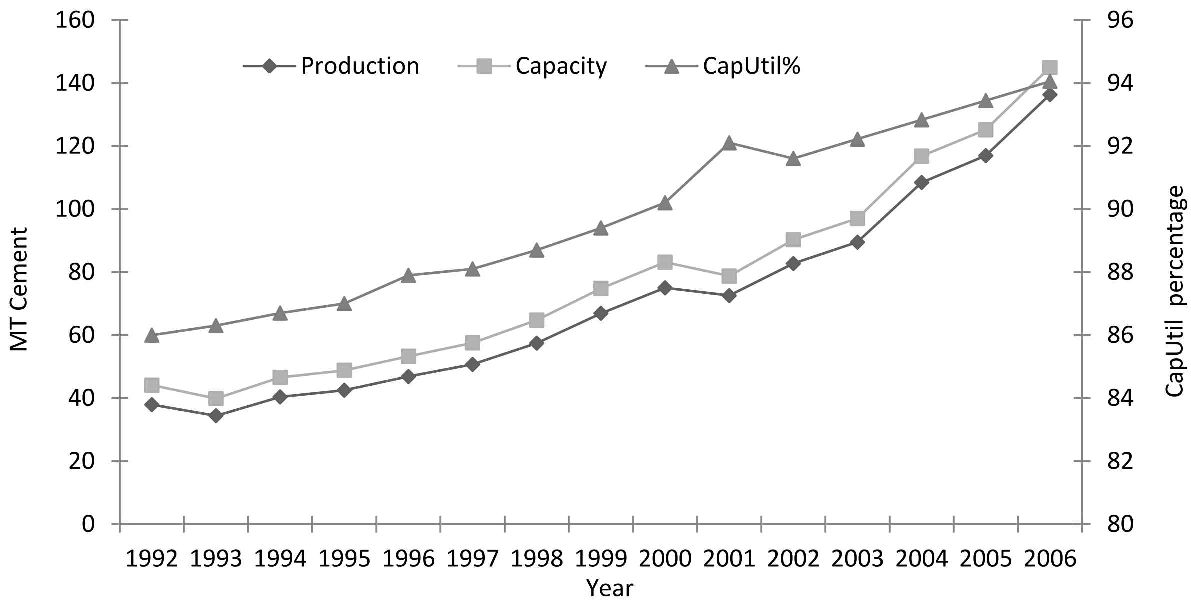

Figure 1. Capacity and production in cement industry

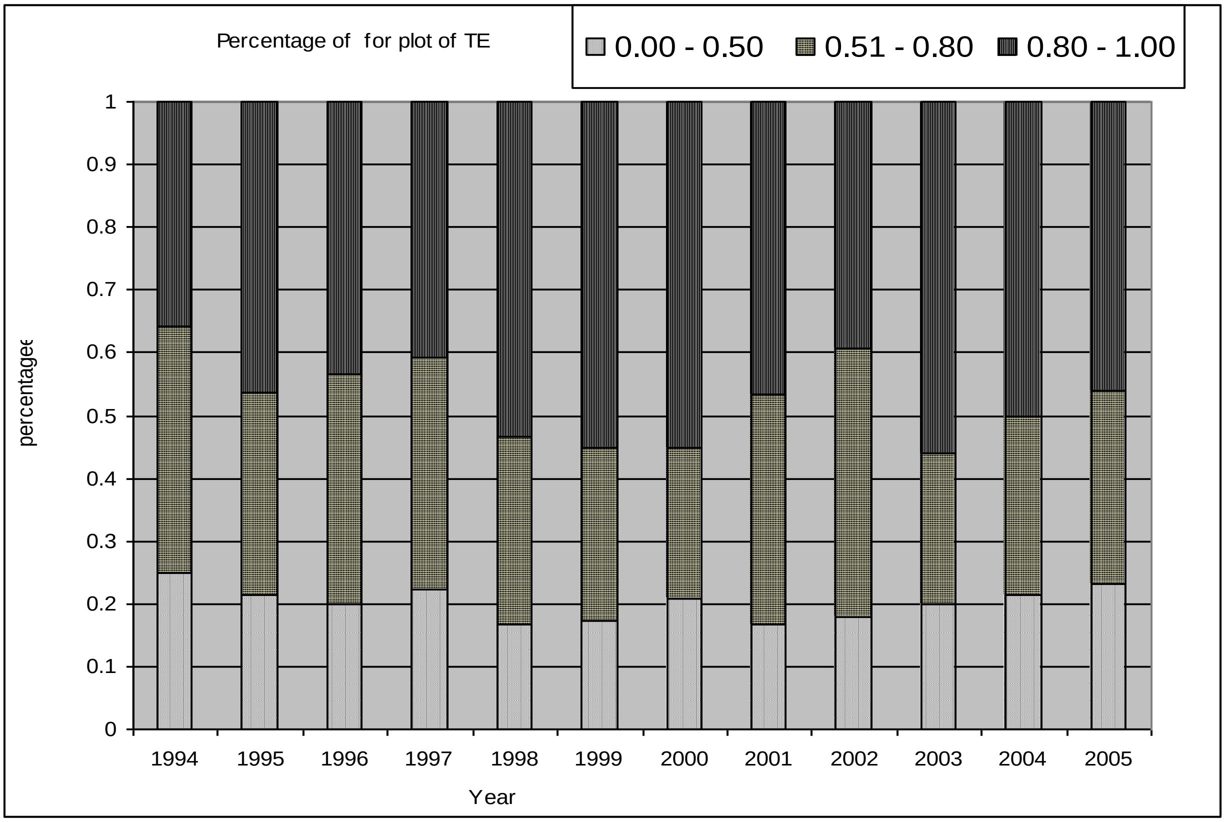

Figure 2. Percentage of firms belonging to different technical efficiency bands

Appendix 1: Firm Code and Name

company name	Firm Code	company name	Firm Code
Ambuja Cement Eastern Ltd.	1	Madras Cements Ltd.	17
Andhra Cements Ltd.	2	Mangalam Cement Ltd.	18
Associated Cement Cos. Ltd.	3	Mysore Cements Ltd.	19
Cement Corpn. Of India Ltd.	4	N C L Industries Ltd.	20
Coromandel Cements Ltd.	5	Narmada Cement Co. Ltd.	21
Dalmia Cement (Bharat) Ltd.	6	O C L India Ltd.	22
Deccan Cements Ltd.	7	Prism Cement Ltd.	23
Gujarat Ambuja Cements Ltd.	8	Priyadarshini Cement Ltd.	24
Gujarat Sidhee Cement Ltd.	9	Sagar Cements Ltd.	25
Hemadri Cements Ltd.	10	Saurashtra Cement Ltd.	26
India Cements Ltd.	11	Shree Cement Ltd.	27
J K Synthetics Ltd.	12	Shree Digvijay Cement Co. Ltd.	28
K C P Ltd.	13	Sri Vishnu Cement Ltd.	29
Kakatiya Cement Sugar & Inds. Ltd.	14	Srichakra Cements Ltd.	30
Kalyanpur Cements Ltd.	15	Suvarna Cements Ltd.	31
Kanoria Industries Ltd.	16		

Appendix 2: Energy and emission conversion rates

Fuel	IPCC default TCO_2/TJ	EU average only CS TCO_2/TJ
Anthracite	98.3	98.7
Coking Coal	94.6	91.1
Other Bit. Coal	94.6	95.1
Sub-bit Coal	96.1	97.1
Lignite	10.2	110
Oil Shale	106.7	107.7
Peat	106.0	99.4
Coke Oven/Gas coke	108.2	105.4
Coke Oven Gas	47.7	42.8
Crude oil	73.3	74.5
Gasoline	69.3	72.6
LPG	63.1	65.0
Naphtha	73.3	73.0
Petroleum coke	100.8	98.3
Petro product	74	
Electricity	316	

*Assuming a conversion efficiency of 24% in the coal-fired thermal power plant, equivalent to the use of 0.72Kg Coal /KWH (as mentioned in Das and Kandpal (1997a), Das and Mehra et.al. (1993), and Mehra and Damodaran (1993)).