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Energy Use Efficiency in Indian Cement Industry: Application of Data Envelopment Analysis and Directional Distance Function

Sabuj Kumar Mandal
S Madheswaran

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ENERGY USE EFFICIENCY IN INDIAN CEMENT INDUSTRY: APPLICATION OF DATA ENVELOPMENT ANALYSIS AND DIRECTIONAL DISTANCE FUNCTION

Sabuj Kumar Mandal[1], S Madheswaran[2]

Abstract

The present paper aims at measuring energy use efficiency in Indian cement industry and estimating the factors explaining inter-firm variations in energy use efficiency. Within the framework of production theory, Data Envelopment Analysis (DEA) and directional distance function (DDF) have been used to measure energy use efficiency. Using data from electronic CMIE PROWESS data base for the years 1989-90 through 2006-07, the study first estimates energy efficiency and then compares the energy efficiency across firms in the Indian cement industry. Empirical results suggest that there is enough scope for the Indian cement firms to reduce energy uses, though this potential for energy saving varies across firms. A second-stage regression analysis reveals that firms with larger production volume have higher energy efficiency scores and that age of the firms does not have any significant impact on energy use efficiency. Also, higher quality of labor force associates with higher energy use efficiency. Finally, Energy Conservation Act, 2001, has not yet had any significant impact on energy use efficiency.

Introduction

The Indian economy exhibited an impressive growth rate of 9.0% and 9.2% during 2005-06 and 2006-07, respectively (MoF 2007). Now, Government of India aims to achieve a GDP growth rate of 10% in the Eleventh Five-year Plan and maintain an average growth rate of about 8% in the next 15 years (Planning Commission 2002). However, energy being a vital element of production, such an ambitious vision of the Indian government would inadvertently call for a rapid increase in commercial energy demand at the rate of 5.2% per year in the near future (Government of India, Planning commission). Various estimates indicate that India would have to increase its primary energy supply by at least three to four times, and its electricity generation capacity by five to six times of the 2003/2004 levels by 2031. The *Integrated Energy Policy* report brought out by the Planning Commission estimates that in a 8% GDP growth scenario, India's total energy requirements would be in the range of 1536 MTOE (million tones of oil equivalent) to 1887 MTOE by 2031, under alternative scenarios of fuel and technological diffusion. Accordingly, India faces a formidable challenge in meeting its energy needs and providing adequate and affordable energy to all sectors of the economy in a sustainable manner.

In formulating its growth strategy for the future India has placed much emphasis on the growth of its manufacturing sector. The objective of the Indian planners is to achieve accelerated growth in the industrial sector (especially manufacturing) with a view to increasing industry's share in

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[1] PhD Fellow, Centre for Economic Studies and Policy, Institute for Social and Economic Change, Nagarabhavi, Bangalore-560 072, E-mail: sabujecon@gmail.com.

[2] Professor, Centre for Economic Studies and Policy, Institute for Social and Economic Change, Nagarabhavi, Bangalore-560 072, E-mail: madhes@isec.ac.in.

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GDP as well as India's share in the worlds industrial output (Mukherjee, 2008). This 'industry driven growth' could be achieved only through massive utilization of energy as the Indian industrial sector consumes a large proportion of primary energy, accounting for 4.5% of industrial energy use worldwide (Gielen and Tailor, 2009). This share is projected to further increase as the economy expands rapidly. Under business as usual, industrial energy use is projected to rise faster than total final energy use. In such a situation it is necessary to put in substantial effort to enhance energy use efficiency of the industrial sector so as to cope with massive demand. With this background, the present study makes an attempt to estimate the energy use efficiency in Indian cement industry which is the highest energy intensive industry among all other manufacturing industries in India.

Indian Cement Industry: Policy changes and massive growth

Indian cement industry witnessed an unprecedented growth as a sequel to government's liberalization policy initiated in the form of partial decontrol in 1982, subsequently culminating in total decontrol in 1989. India has progressed from being the world's eighth largest cement producer in 1979-80 to being the second largest producer at present. However, this huge growth in cement production has been achieved through massive utilization of energy. Among the energy intensive industries in India, cement industry happens to be highly energy-intensive with the second highest share in fuel consumption (15.60%), after Iron and Steel (18.10%), mostly in the form of coal utilization. Its expansion could not have been achieved without a substantial increase in energy uses, mostly in the form of coal.

This has resulted in severe environmental problems not only in the coal mining regions but also around the cement producing plants. In addition, India's annual emission of green house gases from the cement industry has increased from 7.32 mt in 1993 to 16.73 mt in 2003 and its share in total carbon dioxide (CO_2) emission by India has increased from 3.3% to 4.8% during this period (ICRA, 2006).

The Indian government, recognizing the potential dangers of these environmental problems, has made several policy changes over the past 25 years or so to increase the energy use efficiency of the firms and thereby reducing the CO_2 emissions, with particular emphasis on energy-intensive heavy industries such as the cement industry. These policies include (i) disclosing companies' particulars on energy efficiency; (ii) accelerated depreciation of energy efficiency and pollution control equipment; (iii) setting up the Energy Management Centre under the Ministry of Energy; (iv) deregulation to promote industrial competitiveness; (v) energy price reforms to guide energy efficiency initiatives and encourage international competitiveness; and (vi) enforcement of the Energy Conservation Act and Electricity Act (Yang, 2006). As a result, the energy intensity (measured by the ratio of energy consumption to gross value of output) of this industry declined from 0.2446 in 1989-90 to 0.2241 in 2006-07. This decline in energy intensity can be attributed to the energy efficiency policies instituted by the government over this period. Although energy intensity of Indian Cement industry declined over the study period, it is still very high as compared to other energy intensive industries, such as Glass (0.1995), Aluminum (0.1601), Paper (0.1503), Fertilizers (0.1219), Iron &steel (0.0835) and much higher than aggregate manufacturing (0.0396). *So it is necessary to examine whether there is any scope for this industry to further improve its level of energy use efficiency?*

The potential for improving energy efficiency, however, depends on the behavioral objectives of the firms. In this study, we assume three behavioral objectives from the firms' point of view: (i) to reduce all the inputs proportionately, (ii) to simultaneously reduce the inputs and increase the outputs by same proportion and (iii) to choose that particular input bundle which minimizes total input cost. Moreover, firms differ in terms of their age, size, capital-energy ratio, quality of labor force and many other factors. As a result, potential for energy saving varies across firms. So, a second stage regression analysis has been carried out to identify factors explaining inter-firm variations in energy use efficiency.

The rest of the paper is organized as follows. Section 2 provides a brief review of the literature on energy efficiency. Section 3 presents the methodology for measuring energy use efficiency. Section 4 discusses the data and modeling issues. Section 5 presents estimates of energy efficiency obtained from different models. Section 6 explains inter-firm variations in energy efficiency with several firm specific factors along with a case study. Section 7 concludes the study.

A brief review of literature

In the extant literature, energy intensity is defined as the quantity of energy used per unit of output/activity (Mukherjee, 2008) or energy used per unit of value added (Mongia and Sathaye 1998). The inverse of energy intensity is traditionally used as a measure of energy efficiency or energy productivity. A rich body of literature has emerged for examining energy intensity across various end-use sectors. The focus of this body of research has been to develop improved methods to accurately decompose the aggregate energy intensity in the economy into true changes in intensities at the disaggregated sectoral level and the impact of changes in structural composition of the economy (Mukherjee 2008). While majority of these studies focus on the US economy, several others have been carried out with similar analysis for other countries as well.

In the Indian context, however, very few attempts have been made to examine the issue of energy efficiency with analytical rigor. We can divide these studies into two major groups according to their objectives. *The first group* studies concentrate on decomposing energy intensity at the aggregate as well as disaggregate sectoral levels. Bhattacharya and Paul (2001) used a complete decomposition technique to decompose the sectoral changes in energy consumption and energy intensity in India during 1980-1996. Their study reveals that though there was an improvement in aggregate energy intensity, agricultural sector was lagging behind. Tiwari (2000) used an input-output framework to calculate energy intensities for different sectors of the Indian economy for the years 1983-84 and 1989-90. His study reveals that overall coal intensity declined while oil and electricity intensities increased during the study period. *The second group* of studies concentrates on identifying the factors that affect energy related CO_2 emissions. Paul and Bhattacharya (2004) used decomposition method to decompose the observed changes in the energy- related CO_2 emissions into four factors: pollution coefficient, energy intensity, structural changes and economic activity. The results of their study show that economic growth has the largest positive effect on CO_2 emission changes in all the major economic sectors. Emissions of CO_2 in industrial and transport sectors show a decreasing trend due to improved efficiency and fuel switching. The study by Nag and Parikh (2000) also tries to analyze the impact of different factors such as activity levels, structural changes, energy intensity, and fuel mix and fuel quality on the changes in aggregate carbon intensity of the economy for the period 1970-1995. Srivastava (1997) presents some indicators of energy use in India including per capita energy consumption levels, the structure of energy consumption as well as efficiency of its utilization over the recent decades.

So both these groups of studies treat either energy intensity or carbon emission as a proxy for energy use (in) efficiency and try to identify the factors that affect energy intensity/carbon emission intensity by decomposition technique. But inverse of energy intensity is an imperfect proxy for energy use efficiency because, energy intensity may decline not only due to an improvement in energy use efficiency but also some other factors like changes in the production process from being more energy intensive to less energy intensive etc. Since energy is one of the factors of production (capital, labor, material), efficiency in its use can be better analyzed in a production theoretic framework which allows estimating energy use efficiency under different behavioral objectives of the firms. Moreover, production theoretic framework allows examining the scope for further improvement in energy use efficiency. This framework is used by Mukherjee (2008) to examine energy use efficiency in the Indian manufacturing sector for the period 1998-99 to 2003-04 and the U.S manufacturing sector for the period 1970-2001.

Following Mukherjee (2008), the present study also adopts a production theoretic framework to study energy efficiency of Indian cement industry. But our study departs from Mukherjee (2008) in the sense that we first estimate energy use efficiency from input oriented technical efficiency model with an objective of reducing all inputs while keeping output constant. Then we apply directional distance functional approach to allow output to increase while reducing inputs, whereas, the maintained assumption in Mukherjee (2008) assumes output being constant. Moreover, we use firm level data because efficiency and productivity related issues are more relevant in the context of individual firms than the industry as a whole. To the best of our knowledge, the present study is the first of its kind in using firm level data for studying energy use efficiency in the context of Indian industries.

Methodology

In the present study, we use the definition of efficiency given by Farrell (1957), who drew on the works of Debreu (1951) and Koopmans (1951) to define a simple measure of efficiency which could account for multiple inputs. Farrell (1957) proposed that the efficiency of a firm consists of two components: **technical efficiency,** defined as the ratio of *optimal* input bundle to the *actual* input bundle in case of input oriented measure of efficiency, or as the ratio of *actual* output bundle to the *optimal* output bundle in case of output oriented measure of efficiency, and **allocative efficiency,** which reflects the ability of a firm to use the inputs in optimal proportions, given their respective prices and technology. The ‘optimal’ input or output bundle is determined from the production frontier (or cost frontier depending upon the objective of the decision making unit (DMU)). In this respect, the literature provides two alternative approaches- the parametric approach, in which a functional form is specified for the frontier; and the non-parametric approach, in which no *a priori* specification is imposed regarding the functional form of the frontier. Within the non-parametric approach, Charnes, Cooper and Rhodes (CCR, 1978) first developed DEA to measure the efficiency of individual DMUs. CCR model had an input orientation and assumed constant returns to scale. Subsequent papers have considered alternative sets of assumptions, such as Banker, Charnes and cooper (BCC, 1984), in which a variable returns to scale (VRS) model is proposed. This DEA method uses mathematical programming and creates a piecewise linear *best practice frontier* based on the observed input-output data. Since its introduction, DEA has been used extensively to study efficiency of DMUs in different fields. Following Mukherjee (2008), this study uses DEA for estimating energy use efficiency in a production theoretic framework.

Assume a firm producing a single output *y* from a vector of *m* inputs $x = (x_1, x_2, ..., x_m)$ Let y_j output of jth DMU and x_j represent the input bundle of the jth DMU. Suppose that input-output data are observed for *n* DMUs. Then the technology set can be completely characterized by the production possibility set $S = \{(x, y) : y \text{ can be produced from } x\}$ based on a few regularity conditions of feasibility of all observed input-output combinations, and free disposability with respect to inputs and outputs and convexity.

The input oriented technical efficiency measure is defined as the ratio of the optimal (i.e., minimum) input bundle to the actual input bundle of a DMU, for a given level of output, holding input proportions constant. The BCC DEA model for measuring the input oriented technical efficiency of a DMU with the input-output bundle (x_0, y_0) is represented by model 1 comprising (1a) through (1e):

BCC DEA Model:

$$q^* = \min q \quad (1a)$$

Subject to the following constraints:

$$\sum_{j=1}^{n} x_{ij} l_j \leq q x_{i0} \quad (1b)$$

$$\sum_{j=1}^{n} y_j l_j \geq y_0 \ \text{(output)} \quad (1c)$$

$$\sum_{j=1}^{n} l_j = 1 \quad (1d)$$

$$l_j \geq 0, \ j = 1, 2, ..., n \quad (1e)$$

The above model assumes that the objective of the firms is to reduce *all inputs* to the largest extent possible by the same proportion so as to accommodate any potential complementarity between energy and other inputs (Mukherjee, 2008). Note that inequality (1c) ensures that the resultant output is no less than what is actually being produced. Condition (1d) implies that the technology exhibits variable returns to scale (VRS). An efficient DMU will have $q^* = 1$, implying that no equi-proportionate reduction in inputs is possible, whereas an inefficient DMU will have $q^* < 1$

From the above model, the optimal value of q is called input oriented measure of radial technical efficiency defined as ability of the firm to proportionately contract all inputs that is possible for the firm while producing the given output. If the constraint associated with a particular input (say energy) in the above model is non-binding, this would imply that it is possible to reduce this input even further without causing a reduction in output or requiring additional amounts of any other inputs.

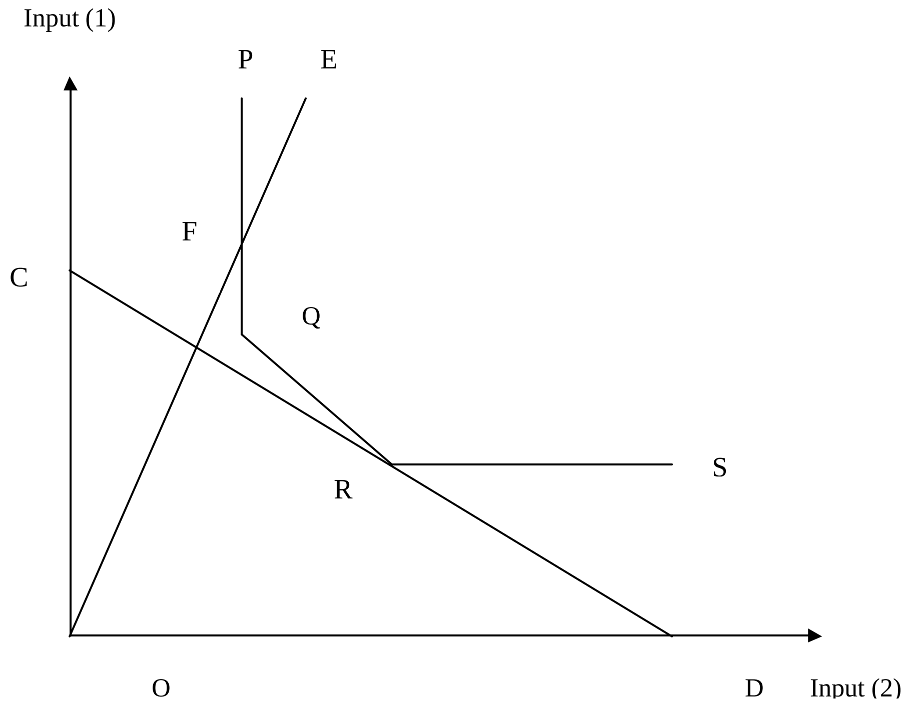

Fig 1: Radial technical efficiency, cost efficiency and energy efficiency

In Fig 1,Suppose that points E, F, Q, R, and S represent input bundles of five DMUs producing the same output level $\bar{y}$, using different combination of two inputs x_1 and x_2. PFQRS represents the piece-wise linear isoquant corresponding to output level $\bar{y}$ and the area to the right bounded by PFQRS is the input requirement set $L(\bar{y})$. Clearly, points F, Q, R and S represent efficient DMUs as they all lie on the isoquant, whereas point E represents inefficient DMU. Suppose we are interested in evaluating the technical efficiency of the DMU represented by point E. In this case, it is possible to proportionately contract the input bundle to F and still produce the given level of output $\bar{y}$. Hence, the ratio of input requirement at F to the input requirement at E provides a measure of radial technical efficiency for the DMU E. Now it is clear from Fig.1 that input x_1 can be reduced even further up to Q so that the point Q represents the slack adjusted efficient point with respect to input x_1. The ratio of the quantity of x_1 used at Q to that at E, provides a measure of slack- adjusted radial technical efficiency of the input x_1 by DMU E.

The previous model for energy efficiency measure is based on the assumption that firms' underlying objective is to reduce all the inputs without reducing the output. But if we allow output to expand then energy efficiency has to be defined as the ability of the producer to reduce all the inputs (including energy) and expand the output by the same proportion. To estimate energy use efficiency when firms' objective is to contract inputs as well as expand output at the same time, we have used *directional distance function* [1] introduced by Chambers, Chung and Fare (1996) based on Luenberger's (1992) *benefit function* .

Let us consider the pair of input-output vectors (x^0, y^0) and a reference input-output bundle (g^x, g^y). Then, with reference to some production possbility set, T, the directional distance function can be defined as follows:

$$\vec{D}(x^0, y^0; g^x, g^y) = \max b : (x^0 + bg^x, y^0 + bg^y) \in T.$$

The value of b represents the distance between the observed input-output bundle A(x^0, y^0) and an input-output bundle represented by a point D on the production frontier, $(x^0 + bg^x, y^0 + bg^y)$. The direction vector, $g = (g^x, g^y)$, determines the direction in which observed interior input-output bundle is projected on the frontier,i.e., the direction in which efficiency is measured. Choice of the bundle (g^x, g^y) is arbitrary. As suggested by Chambers, Chung, and Fare (1996), we may select $(-x^0, y^0)$ for (g^x, g^y) and in that case, the directional distance function becomes

$$\vec{D}(x^0, y^0) = \max b : \{(1-b)x^0, (1+b)y^0\} \in T.$$

In other words, we want to increase the output and reduce the inputs by the proportion b . For example, if b equals 5%, we can expand outputs by 5%, while at the same time contracting all the inputs by 5%. This is depicted in Figure 2.

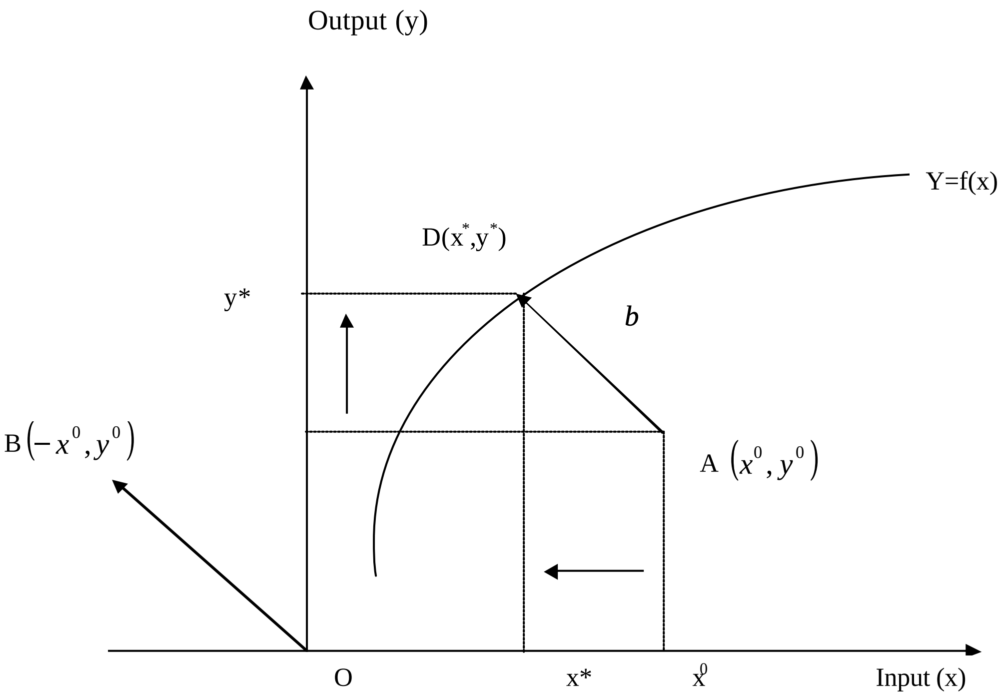

Fig. 2: Directional distance function

In Fig.2, point A shows the actual input-output bundle (x^0, y^0) while point B represents $(-x^0, y^0)$. Point D on the production frontier is the projection of point A in the direction of OB. Point D represents the bundle (x^*, y^*) where $x^* = (1-b)x^0, y^* = (1+b)y^0$ .A movement from point A towards D indicates an improvement in energy efficiency, because D represents a higher level of output with lower level of energy requirement as compared to A. The value of the directional distance function, b , is obtained by solving the following maximization problem:

DEA model (2):

Maximize b (2a)

Subject to $\sum_{j=1}^{N} l_j y^j - b y^0 \geq y^0$; (2b)

$$\sum_{j=1}^{N} l_j x^j + b x^0 \leq x^0 ; \quad (2c)$$

$$\sum_{j=1}^{N} l_j = 1; \quad (2d)$$

$$l_j \geq 0 (j = 1,2,.....,N); b \text{ unrestricted} \tag{2e}$$

This is a straightforward Linear Programming Problem and can be solved easily. The factor b measures the level of technical inefficiency of the firm and (1- b) measures the technical efficiency.

However, sometimes, firms' objective is not to reduce all the inputs by same proportion but to choose that particular input bundle which would minimize the total input cost for a given level of output. So this cost minimization may also call for saving energy input if it is more valuable than other inputs. During the periods of high energy prices, achieving cost effectiveness would call for substituting other inputs for energy. Let us consider Fig. 1 once again. Given the input prices faced by DMU E, it will operate at point R where isocost line CD is tangent to the isoquant, i.e. total input cost is minimized. It is clear from Fig.1 that at point R input proportion is different from that at E. Specifically cost minimization in this case calls for substituting input 2 for input 1 (say energy).

Suppose that the given input price vector for the DMU under evaluation is w_0 . The DEA model for cost minimization can be written as in model 3, which comprises (3a) – (3e)[2]:

DEA model (3):

$$C^* = \min w_0^{/} x \quad \text{(Total input cost)}, \tag{3a}$$

Subject to

$$\sum_{j=1}^{n} x_{ij} l_j \leq x_i \quad (i = \text{labor, capital, energy, materials}), \qquad (3b)^3$$

$$\sum_{j=1}^{n} y_j l_j \geq y_0 \quad \text{(Output)} \tag{3c}$$

$$\sum_{j=1}^{n} l_i = 1, \tag{3d}$$

$$l_j \geq 0, j = 1,2,....n . \qquad (3e)^4$$

In model (3), the objective of the firms, as mentioned earlier, is to minimize the total input cost. The inequalities (3a) and (3c) ensure that the optimal input bundle is chosen in such a way that total input cost is minimized, but output at this optimal level is no less than what was being produced earlier. The ratio of minimum cost (C*) obtained from model 2 to the actualcost (C) firms incur, gives a measure of cost efficiency of the DMU, i.e., CE = C*/C. Further, the ratio of cost minimizing energy use to the actual level of energy firms use, gives a measure of energy use efficiency based on cost minimization motive. Since cost minimization allows for substitution of other inputs for energy, it can be expected that potential energy saving in this model would be greater than that of model (1). But the objective of cost minimization does not always lead to energy conservation. During the period of low energy prices, firms tend to substitute energy for other inputs and in that situation cost minimizing energy use would be greater than actual energy use. For this reason estimated value of energy efficiency obtained from this model may be greater than 1, unlike in model (1).

Data Consolidation and Construction of the Frontier and Modeling issues

The main data source for the study is the electronic PROWESS data base created by Centre for Monitoring Indian Economy (CMIE). PROWESS provides all kind of financial information for the companies from their annual balance sheet. PROWESS data for value of output, gross value added, wages and salaries, expenses for power and fuel and expenses for raw material are in nominal terms. Using appropriate price index series (RBI wholesale and consumer Price Index), we have converted the nominal values to the real values at 1993 prices. The period chosen for the analysis in the present study is 1989-90 to 2006-07 and unbalanced panel of 70 firms has been constructed for the study. Total number of observations is 887. Of the 70 firms, there is one Central Govt. Enterprise (Cement Corpn. Of India Ltd.), two State Govt. Enterprises (Tamil Nadu Cements Corpon. Ltd and Travancore Cements Ltd.) and the remaining firms are private sector enterprises. In each year, the selected firms produce more than 75% of the industry output and consume more than 80% of total energy consumed by the whole industry. So our sample of firms may be considered as a representative sample for the industry. Gross value of output has been used as an index of output. We prefer value of output as an index of output in place of gross value added because in the production process we have included material and energy which are intermediate inputs. Moreover, gross value added is negative for a huge number of firms, reducing the number of sample to a greater extent. Nominal value of Gross value of output has been converted to real values at 1993 prices by using wholesale price index for cement.

Of the inputs, material and energy are entered as expenses for material and power and fuel respectively. Material input is deflated by the price index of non-metallic mineral product, and energy input is deflated by the composite price index of fuel, power, light and lubricants. To construct capital stock, we have used the gross fixed asset. Following Goldar (1986), we have preferred gross fixed asset to net fixed asset, because depreciation charges in the Indian industries are known to be highly arbitrary, fixed by income tax authorities and hardly represent actual consumption. The standard Perpetual Inventory Method (PIM), suggested by Balakrishnan and Pushpangadan (1994), has been used to construct the capital stock with 1995-96 as the benchmark. In the absence of information regarding input prices faced by the individual firms in different states, all India price indexes for the inputs are used as a proxy for input prices, and it is assumed that in a perfectly competitive input market all firms are facing the same input prices.

Next, we need to discuss the construction of the production frontier based on which efficiency is measured. First of all, we assume that variable returns to scale hold. Secondly, for each year we construct a sequential frontier which assumes all current and past observations as feasible. Starting with a reference sample of 32 observations for the year 1989, we successively enlarge the reference sample by including the observations of one more year. For example, sample firms for 1990 consist of firms available in 1989 plus the existing firms in 1990. Conceptually, a sequential frontier amounts to assuming that there is no technical regress, and that any technical regress will be assimilated with inefficiency by this construction.[5]

Empirical results

Radial technical efficiency (TE) and slack adjusted energy efficiency (EE)

First of all, we have estimated the radial measures of input oriented technical efficiency from our model assuming VRS technology. Next, by accounting for the slacks associated with the constraint for energy in model 1, energy efficiency has been calculated. Table 1 presents both average radial technical efficiency and slack adjusted energy efficiency of the cement companies during the study period.

Table 1: Average radial technical efficiency (TE) and slack adjusted energy efficiency (EE)

Year	TE	EE
1989-90	0.8382	0.7975
1991-92	0.8154	0.7962
1993-94	0.7596	0.7513
1995-96	0.7788	0.7632
1997-98	0.7694	0.7524
1999-00	0.7683	0.7579
2001-02	0.7943	0.7888
2003-07	0.7853	0.7780
1989-07	0.7887	0.7732

Source: Author's Calculation

It can be seen from Table 1 that overall technical efficiency of the firms under study during the sample period is 0.7887, implying that it would be possible to contract all the inputs (including energy) proportionately by 21.13% and still produce the given level of output. The average energy efficiency of the firms under study during the sample period is 0.7732, implying that after reducing all inputs proportionately by 21.13%, it would be possible to further reduce the energy input by 28.68% and still produce the given level of output, without using more of any inputs.

Energy use efficiency based on 'directional distance function'

Energy efficiency, based on the assumption of simultaneous expansion of output and contraction of input, has been estimated by solving the maximization problem mentioned in model (2). We have first estimated the value of b which represents the level of technical inefficiency of the Indian cement companies. Then subtracting b from 1, we have estimated the value of technical efficiency. The estimated efficiency scores are presented in Table 2. Average annual technical efficiency of the cement companies during the sample period of our study is 0.8955 which implies that it would be possible to simultaneously increase the output by 10.45% and reduce energy and all other inputs by 10.45%. So energy use efficiency of the Indian cement firms is 89.55%, indicating that firms are not using energy with 100% efficiency and that there is potential for energy saving through efficiency improvement.

Technical efficiency score starts at 0.9051 in 1989-90 and reaches the maximum level of 0.9152 during the period 2001-02. The high value of technical efficiency or energy use efficiency during the period 2001-02 can be attributed to the implementation of Energy Conservation Act, 2001. However, this high value of energy efficiency has not been sustained in the subsequent years and infact starts declining thereafter and ends up with 0.8858 during the last sub- period of our study, 2005-07.

Table 2: Average technical efficiency (TE) based on directional distance function

Year	TE
1989-90	0.9051
1991-92	0.8886
1993-94	0.8914
1995-96	0.8661
1997-98	0.9029
1999-00	0.9004
2001-02	0.9152
2003-04	0.9038
2005-07	0.8858
1989-07	0.8955

Source: Author's estimation

Energy use efficiency based on cost minimization

From an economic perspective, however, it is not sufficient to achieve technical efficiency. Total economic efficiency consists of technical efficiency as well as allocative efficiency where the latter is the ratio of cost efficiency and technical efficiency. Since, overtime, prices of different inputs change at different rates, a DMU would need to change input proportions in response to relative price change in order to be cost efficient. Inappropriate application of input proportions leads to allocative inefficiency which in turn leads to cost inefficiency. Given the input prices, Model (2) allows for estimating cost efficiency of the DMUs. Table 3 presents average cost efficiency (CE) and energy efficiency based on cost minimization (cost min. EE) motive.

Table 3: Average cost efficiency (CE) and cost minimising energy efficiency

Year	CE	Cost min EE
1989-90	0.6240	0.9491
1991-92	0.6209	0.9576
1993-94	0.5743	0.9677
1995-96	0.4935	0.9282
1997-98	0.4911	0.8532
1999-00	0.4437	0.9014
2001-02	0.4481	1.0206
2003-07	0.4451	0.9318
1989-07	0.5176	0.9387

Source: Author's calculation

The ratio of optimal energy use obtained from model (3) to the actual energy use provides us a measure of energy efficiency. For example, let x^* be the cost minimizing energy requirement and x be the actual energy use, then the ratio $\frac{x^*}{x}$ gives a measure of energy use efficiency based on cost minimization. Table 3 reveals that average cost efficiency is as low as 51.76%. Since cost efficiency is the product of allocative and technical efficiency, and estimated technical efficiency being as high as 78.87%, it can be inferred that there exists a significant amount of allocative inefficiency in Indian cement industry, implying firms have been unable to apply inputs in proper proportion. When input prices are taken into consideration, the annual average energy efficiency of the Indian cement firms turns out to be 93.87% which is much higher than the measured cost efficiency of 51.76%. A higher energy efficiency than cost efficiency suggests that at the cost minimizing input bundle cement firms should be conserving more of other inputs rather than energy (Mukherjee,2008). In the sub period 2001-02, the measured energy use efficiency was the highest among all other periods. In 2001, the Government of India enacted Energy Conservation Act which would facilitate and enforce efficient use of energy and its conservation in this industry earmarked as 'designated consumers' of energy (Nandi and Basu, 2008). In this sub period energy efficiency exceeds 1, implying that in order two minimize costs, firms should have used more energy than what actually they did in this period. Moreover, the overall average energy efficiency from this model is also higher than the one obtained from model (1). Comparing the energy efficiency scores obtained from model (1) and model (3) (reported in Table 1 and Table 3), we find that energy efficiency scores, obtained from cost minimization, are substantially higher than that obtained from radial technical efficiency model (1). Now it is worth examining why the energy use efficiency based on cost minimization is so high in Indian cement industry. The major difference between model (1) and model (3) lies in the fact that in model 1, we assume energy and non-energy inputs are complement to each other. So in this set up, input substitution is not possible. But model (3) calls for input substitution whenever present input proportions are allocatively inefficient. It is, therefore, necessary to examine the extent to which substitution is possible between energy and other non-energy inputs. The role of energy in the structure of production and inter-factor relationship have been the focus of a number of studies, but the evidence on factor and fuel substitutability is mixed. Berndt and wood (1975), Hudson and Jorgenson (1974), Fuss (1977), and Magnus (1979) all worked with data for a single country and found that while energy and labot were substitutable, energy and capital were complementary. Griffin and Gregory (1976) used cross-section data at five- year intervals for nine countries to capture long-run effects and found energy and capital to be substitutes. In the context of Indian cement industry, Roy, et.al (1999) found substitutable relationship between capital-energy and labor- energy but material and energy were found to be complementary. So capital and labor can be substituted for energy. In this study, the significantly higher energy efficiency measures from model (3) indicate that it is possible to substitute other inputs for energy for minimizing total input cost.

Explaining inter-firm variations in energy use efficiency

To explain the observed variations in energy use efficiency across the firms during our sample period, we employ a regression analysis. The estimated energy efficiency scores are used as dependent variable and several firm specific factors as independent variables in the regression analysis.

A crucial factor that leads to inter-firm variations in energy efficiency is firm's size. The size of a firm affects its performance in many ways. Larger firms have grater capability to diversify their business and exploit economies of scale and scope. By making their operations more effective, these characteristics help them generating superior performance relative to the smaller ones (Penrose, 1959). Alternatively, size is correlated to market power (Shepherd, 1986) which increases the possibility of generating X-inefficiency in production, leading to relatively inferior performance (Leibenstein, 1976). Theory, therefore, does not establish any unique relationship between firm size and its performance. In this context, therefore, it is worth examining how firm size affects energy efficiency of the cement companies. Following Lundvall and Battese (2000), intermediate input is used as a proxy for firm size in this study. This variable is more highly correlated to output, the ideal size variable, than labot and capital. Hence, this variable in our model is both an input in the frontier, and a factor associated with deviations from the same frontier due to technical inefficiency. To examine any non-linearity in the relationship between SIZE and energy efficiency, we have included both SIZE and square of size, i.e., SIZE Sq as independent variables in the regression analysis.

Another important factor that may also affect firms' performance in energy efficiency is age of the firm. Theory relating firm's age with its performance is again ambiguous in nature. Some scholars suggest that older firms enjoy superior performance since they are more experienced, and have enjoyed the benefits of learning and are not prone to the liabilities of newness (Stinchcombe, 1965). On the contrary, there is a counter argument that the older firms are prone to inertia and are less likely to have the flexibility of rapid adaptation in changed economic circumstances. As a result, they are more likely to lose out on the performance stakes to younger and more agile firms (Marshall, 1920). We have calculated firm's age in a particular period by taking the difference between that particular period and its incorporation year.

Quality of labor force may also contribute to the differences in energy efficiency (Walton, 1981). We have included the variable LPROD which measures labor quality in terms of labor productivity (i.e., output per unit of wages and salaries[6]). We would expect a higher quality labor force to be associated with more efficient use of energy. Sometimes, energy saving and the resultant improved energy efficiency may become a capital intensive process, and in that case, a higher capital-energy ratio would be associated with higher energy efficiency. However, empirical literature provides ambiguous relationship between capital and energy. In some cases, capital and energy are substitute while they are complementary to each other in some other cases. Therefore, we have included capital-energy ratio KE as an independent variable which could have either a positive or a negative coefficient.

Finally, we have added the dummy variable D1 to test whether Energy Conservation Act, 2001 has brought about any significant change in the level of energy use efficiency of the cement companies. D1 takes the value zero for all the years preceding 2001 and one for all the successive years including 2001.

To explain the observed variations in energy efficiency obtained from model (1) and model (2), Tobit regression is used. Tobit model is the appropriate method when the dependent variable is censored.[7] Since the technical efficiency scores can not exceed 1, the dependent variable is right censored at 1. On the other hand, the energy efficiency measures obtained from cost minimization model are not censored and so OLS is an adequate procedure.

The results from the regression analysis are reported in Tables 4, 5 and 6. As can be seen from the results, SIZE variable has a positive and significant coefficient, implying larger the firm size, greater is the energy efficiency. A negative coefficient of SIZE Sq. implies that with the increase in size, energy efficiency first increases then decreases after reaching a certain size. Age of the firm is not significantly affecting firms' performance in energy efficiency obtained from all the three models. The coefficient of capital-energy ratio KE is positive and significant in the three models, implying energy saving and thereby improving energy use efficiency is a capital intensive process. Also, LPROD has a positive and significant coefficient in both the model, implying that firms with higher quality of labor experience higher energy efficiency. This result is in line with that of Mukherjee (2008) in the context of Indian manufacturing sector. Finally, Energy Conservation Act, 2001 has not yet had any significant impact in terms of achieving higher energy efficiency.

Table 4: Random effect Panel Tobit regression for explaining energy efficiency based on model (1)

Parameter	Coefficients
Intercept	0.6401*(0.0347)
SIZE	0.0370*(0.0044)
SIZE Sq	-0.0005*(0.0001)
AGE	0.0027(0.0018)
KE	0.0021*(0.0004)
LPROD	0.0024*(.0002)
D1	-0.0132(0.0084)
Log likelihood	175.0569

Note: Figures in the parentheses are standard error. * implies significance at the 1% level.

Table 5: Random effect Panel Tobit regression for explaining energy efficiency based on model (2)

Parameter	Coefficients
Intercept	0.8181*(0.0158)
SIZE	0.0243*(0.0023)
SIZE Sq	-0.0004*(0.00007)
AGE	-0.0022 (0.0003)
KE	0.0011*(0.0002)
LPROD	0.0016*(.0001)
D1	-0.0137(0.0083)
Log likelihood	349.24

Note: Figures in the parentheses are standard error. * implies significance at the 1% level.

Table 6 : Random effect Panel regression for explaining cost minimizing energy efficiency

Parameter	Coefficients
Intercept	0.6132**(0.2862)
AGE	-0.0090 (0.0069)
SIZE	0.0554* (0.0230)
SIZE Sq.	-0.0012* (0.0002)
KE	0.0202* (0.0013)
LPROD	0.0115* (0.0039)
D1	- 0.1290 (0.1119)
R-sq. (overall)	0.1934

Note: Figures in the parenthesis are standard error. *,** implies significance at the 1% and 5% level respectively. Random effect model has been adopted after conducting Hausman specification test. Hausman test provides $c^2_{df=6} = 9.09$ and Prob > c^2 = 0.1685. So the null hypothesis (H_0): difference in coefficients between fixed effect and random effect model can not be rejected and we go for random effect model.

But there are several other factors, for example, composition of energy, quality of coal used, production technology, type of cement produced etc., that also can explain inter-firm variations in energy use efficiency. We could not include these factors in our model because unavailability of systematic data for these factors at the firm level. Nevertheless, we have conducted a case study of ACC Cement Company to understand the importance of these factors.

Associated Cement Company (ACC) Limited: A case study

According to our analysis, energy efficiency score of ACC Limited has been 1 for almost all the years, implying that this company has used energy with 100% efficiency throughout the years. The company has its own energy management cell headed by a certified energy manager. The company imports a major share of its coal stock from South Africa. This imported coal has a higher calorific value than our indigenous coal. To save energy as well as mineral raw material for cement production, ACC has embarked wholeheartedly on a new path of promoting the use of Alternate Fuel and Raw Materials (AFR) through waste management solutions by setting up its AFR cell in August, 2005. The cell is headed by a member of top management and functions under the direct stewardship of the Managing Director. As alternative fuels, it has been using sludge from Iron and Steel industry, paint sludge from automobile industry and process residue from pharmaceutical industry. The following are some highlights of the initiatives taken by ACC's AFR business, some of which are in association with Holcim and GTZ of Germany:

(a) A formal policy framework to promote the use of alternative fuels and raw materials
(b) Each of the cement plants has been mapped for its AFR profile.
(c) Installation of machinery and equipment for AFR feeding wherever required.
(d) AFR awareness programs are conducted in all the plants.
(e) Establishment of Regional Sustainable Development Federations (RSDF) in North, East and Southwest India.
(f) Identification of wastes generated by other industries across the country to examine the feasibility of co-processing these wastes in their kilns, dryers and captive power plants.

(g) Testing of hazardous waste samples to assess the scope of their usage as AFR.

(h) A massive Jatropha and Castor Tree Plantation scheme to plant 5 million trees in phases. Fruits and seeds of these trees serve as replacement fuel. The plantations can supply biomass equivalent to about 50,000 tons of coal over a period of four years.

(i) Effective lobbying and dissemination of information through articles, seminars and lectures to encourage greater acceptance of co processing as a preferred form of waste disposal as compared to incineration.

(j) ACC's AFR team is working closely with Government, Central and State Pollution Control Boards to help popularize co processing of waste in cement kilns.

(k) ACC's AFR team is represented on the Technical team of India's 11th Five Year Plan which will consider AFR as a national initiative.

ACC has also started utilizing another hazardous waste namely; fly ash from thermal power plants to manufacture Portland Pozzolana Cement (PPC). Fly ash is a substitute for clinker which requires the largest share of energy for its production. So, by substituting Fly Ash for clinker, ACC saves a huge amount of energy. In December 2005, ACC was recognized and felicitated by three ministries of the Government of India (Power, Environment & Forests and Science & Technology) for registering the country's highest utilization of fly-ash.

Conclusion

This paper makes an attempt to measure energy use efficiency of the cement firms in India over the period 1989-90 to 2006-07 from a production theoretic framework, adopting DEA and DDF technique and using CMIE PROWESS Data base. Depending upon the objectives of the firms, three alternative models have been formulated for estimating energy use efficiency. The first model is radial technical efficiency model which assumes that firms' objective is to reduce all the input proportionately, while the second one assumes that firms' objective is to simultaneously expand the output and reduce the inputs by same proportion. The third model assumes that firms are motivated by cost minimization and that they choose that particular input bundle which minimizes total input cost. Empirical results indicate the existence of energy use inefficiency, implying that Indian cement firms are not able to use all the consumed energy efficiently and there is scope for improvement in energy use efficiency and thereby saving energy. Potential for energy saving, however, depends on the behavioral objectives of the firms. Compared to cost minimization model, energy saving potential is much higher in technical efficiency models, which quantifies the theoretical proposition that technical potential is higher than economic potential. This discrepancy suggests that the relative price of energy in the context of Indian cement industry does not capture the full social cost of using energy and makes energy a relatively cheaper input. A second stage regression analysis reveals that firms with greater size have the higher energy efficiency while age of the firms does not have any significant impact on energy efficiency. Capital-energy ratio (KE) turns out to be positive and significant implying energy saving is a capital intensive process. Also, higher quality of labor force (LPROD) of the firms associates with higher energy use efficiency. Finally, Energy Conservation Act, 2001, has not yet had any significant impact on achieving higher energy use efficiency.

Limitation of the paper lies in measuring the energy input. We have measured energy in terms of expenditure on power and fuel. We would, however, have preferred the physical measurement of energy with appropriate break ups because energy as an input constitutes power, fuel, coal etc. and composition of fuel does matter in energy use efficiency. In the absence of information regarding physical quantity of energy used by the firms, we have used this proxy. Nevertheless, our present study, using data envelopment analysis and directional distance function, highlights the possibility of further improvement in energy use efficiency by the Indian cement firms.

End Notes

1 For a detailed exposition of directional distance function, see Ray (2004).

2 Mukherjee (2008) uses a similar model in the context of Indian manufacturing sector. But in her paper technology is assumed to exhibit CRS while we are assuming VRS technology; since we are using firm level data in our analysis, VRS is the appropriate nature of technology that can be assumed.

3 All the inputs used in the cost minimization model are in expenditure form. We would have preferred to use physical quantity measures but they are not available at the firm level. We hypothesise that the use of value measures are unlikely to introduce much bias in our measures because price of these inputs does not vary much across firms in a competitive input market.

4 See Ray (2004) for a detailed exposition of different DEA models.

5 The assumption of no technical regress seems to make sense for the sample years under study during which most of the cement companies did experienced significant technological improvement.

6 This definition of labor is based on the assumption that wages are paid according to the value of marginal product. The better measure for LPROD would have been output per worker or output per man-hour. Due to unavailability of firm level data for number of workers or man-hours we have used this definition of labor productivity.

7 The observed efficiency score is right censored at 1 as it is equal to the actual (latent) score whenever the actual score is <1 when the actual score is ≥ 1, the observed efficiency score $=1$

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