



# DEA Window Analysis with slack-based measure of Efficiency in Indian Cement Industry

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**Abstract** In data envelopment analysis (DEA), the concept of efficiency is examined either in radial measure or in non-radial measure. Radial measure gives the proportion or a percentage by which all the inputs (outputs) to be reduced (increased) simultaneously, while as the non-radial measure deals directly with the input output slacks which must be minimized, hence inputs and outputs need not to be optimized by same proportion. Radial measures often provide a weak efficiency score while as there is no such case for Non-radial models. The aim of this paper is to employ the non-radial measure (Slack-based model) in DEA window analysis to measure the Technical Efficiency change over years of various Indian cement companies. The research is based on unbalanced panel data of Indian cement companies during the period 2005-15. DEA window analysis is used to determine the efficiency of cement companies and to observe the possibility of changes in the technical efficiency over time. A study is conducted to evaluate the efficiency of cement companies in India in order to identify the sources of inefficiencies and formulate proposals for improving the productivity of those companies and their operations through a three-year window analysis.

**Keywords** Data Envelopment Analysis, Non-Radial Models, Slack-Based Measure, DEA Window Analysis, Indian Cement companies

**AMS 2010 subject classifications** 90C15, 68C05

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## 1. Introduction

The aim of this paper is to evaluate the Technical efficiency change over time from the period 2005 to 2015 of various Indian cement companies by employing extended Data Envelopment Analysis (DEA) approach. As conventional DEA models evaluate efficiency for a particular period and fails in cross sectional and time varying data, this paper employed an extended DEA approach, specifically DEA window analysis for the efficiency assessment of cement companies of India over the defined period. On the other hand there are two basic approaches of DEA one is Radial approach and other Non-Radial approach. In Radial approach all inputs and outputs are to be optimized (Depends upon the orientation of the problem) by the same specified proportion to become efficient, while in non-radial approach this proportion is different from one output to another or one input to another. For example, in radial case, if there are three inputs and two outputs, then in input orientation if the efficiency score comes to be 0.90 by solving the corresponding programming problem, then the evaluated DMU has to reduce all inputs by 10 percent in input orientation case, while in non-radial case three inputs can be reduced by different proportions. If the DMUs are on optimal scale (scale efficient), then both approaches will give same value, otherwise non-radial measure is better than radial one. Since the cement companies are not working on optimal scale, it is good to use some non-radial method to evaluate the efficiency. A DMU which comes to be efficient at a

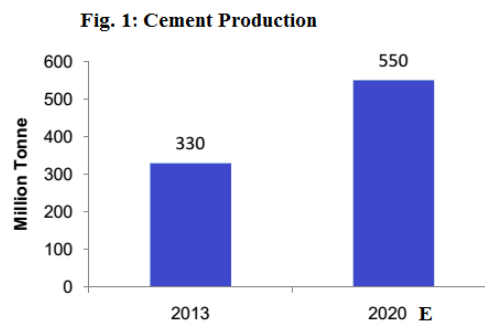
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particular time period may or may not be efficient for other period. Both of above mentioned methods deals with particular period, and van not be used in time varying and cross section data to estimate the efficiency change over different time periods. To estimate the efficiency change over time a method was proposed by [6] and called it as DEA Window Analysis Approach. This method based on radial approach evaluates the efficiency change of DMUs over time. Here in this study, we proposed a non-radial model called as Slack-based model (SBM) for window analysis Approach. The SBM model was first proposed by [24]. We proposed the SBM model for window analysis methodology, to estimate non-radial efficiency change over time. Later we applied the proposed the DEA window analysis based on the Slack-Based Model (SBM) to measure SBM efficiency change over time 2005-15 of various Indian cement companies. The contribution should be able to see the companys efficiency evolves over time and to see whether any size effect exists in the cement company efficiency. This analysis provides trends of efficiency and the rank of each cement company evaluated in terms of its effectiveness. The obtained results allow for analyses of trends of the overall cement sector efficiency. By this approach, the SBM efficiency is analyzed sequentially with a certain window width (i.e. the number of years in a window) using a panel data of the Indian Cement companies. The main idea is to capture the temporal impact on cement efficiency and see its short-run evolution from one window to another.

The remainder of this paper unfolds as follows. Next section describes the empirical literature about cement companies of India and some literature on Window analysis. Third section presents the methodology of SBM DEA with window analysis. Section four describes the data analysis of cement companies. last part includes the conclusion of the paper.

## 2. Literature survey

In recent times cement has become second most consumed substance after water. it is produced from limestone, shell and clay and processed on the temperature of more than 1000 degree Celsius. it is the main ingredient of construction. without it concrete construction is impossible. so utmost care should be taken to improve this industry. off course this industry release a large amount of  $CO_2$  especially in china and India, which is an undesirable output and should be taken into consideration while trying to maximize the production. To achieve high growth rates of GDP in a sustainable manner, India has to place 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 GDP as well as India's share in the worlds industrial output. However, the indigenous Indian cement industry traces its history back to 1914, at the time the market was dominated by imports. Today, the Indian cement industry is very large and second to China in terms of installed capacity. Figure (1) shows the cement production of India in 2013 and its estimated value in 2020.



It has grown at a very fast pace in recent years. Since 1992 India's cement production has more than quadrupled from around 50Mt/yr to 220Mt/yr. The Indian cement industry is now globally competitive with lowest energy consumption and  $CO_2$  emissions. Apart from fulfilling domestic cement requirements, the industry also exports cement and clinker to around 30 countries across the globe. As per of 2011 there were 137 large and 367 mini cement plants in India. In this study we have selected 28 leading producers in order to measure their energy

intensity, which is the quantity of energy used per unit of output. A large amount of literature is available for examining energy intensity of cement industries. [16] estimates the environmental efficiency with  $CO_2$  as undesirable output for interstate data. Their results show that Indian cement industry has a potential to expand desirable outputs and contract undesirable outputs with the given inputs. [17] measures the energy efficiency of Indian cement industry and estimates the factors explaining inter-firm variations between the periods 1989-90 to 2006-07. [3] 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, the agricultural sector was lagging behind. [12] used several DEA models for measuring energy use efficiency of the manufacturing sectors in USA and India. [22] uses the double frontier approach in two-stage DEA case to evaluate the efficiency of various commercial banks through SBM models. [9] used mixed orientation approach to find the efficiency of Decision Making Units. There is a rich body of research to examine energy intensity across various sectors. There are so many ways to examine the efficiency of a production process, but the way DEA finds the efficiency it has gained popularity in energy efficiency analysis.

[4] developed a non-parametric model the relative efficiency of DMUs producing same outputs using same inputs. This model evaluates the efficiency for a particular time period, and hence can not be used in case of cross sectional and time varying data. Obtaining Technical efficiency for time varying data and evaluating efficiency change over time was the concern to researchers. [6] originally proposed DEA Window Analysis approach as a method to evaluate efficiency change in cross sectional and time varying data. Later so many studies were done on window analysis to estimate the efficiency change. For example, [18] applies the DEA window analysis on the data of the Czech commercial banks and to examine the efficiency of the Czech banking sector during the period 2003-2012. In their analysed period, the average efficiency under constant return to scale reached 70-78 % and average efficiency under variable return to scale reached 84-89 %. Similarly, [11] measure the efficiency of East and West African major ports over time by using the Data Envelopment Analysis (DEA) Window Analysis. The analysis revealed total average efficiency level of ports of each of the two regions being below 80%, it means that these ports are in general not really efficient. The ports with the lowest level of efficiency should expand their customer base and increase the public and private investment. This approach has been applied almost in all profit and non-profit organizations. [28] examines the operating efficiency of U.S. hotels with various types, geographic locations, sizes, and room rates from a dynamic perspective by analyzing the efficiency stability and trend from year 2007 to year 2014. [1] evaluates the energy efficiency and productivity growth in the industrial sector over the period of 1999 till 2013 using DEA Window Analysis. DEA Window Analysis was also applied in the cases where outputs are undesirables, as [27] focused on evaluation of China's regional total-factor energy and environmental efficiency within a joint production framework of considering both desirable and undesirable outputs, as well as energy and non-energy inputs. DEA window analysis is employed in some of these instances but when the study horizon is long and the DMUs environment is heavily affected by technological change, one should use a Malmquist index approach as well. [2] used this approach to deal with the less number of DMUs for efficiency evaluation of Canadian Banking Industry for the period of 1981-2000. Usual DEA gives the efficiency only for a given year, but in case of panel data we can not use DEA for detecting efficiency within a given interval of time. Thus, it is useful in detecting performance trends of a decision making unit over time. Each DMU is treated as a different unit in a different period which can increase the number of data point. But the model used is a radial measure given by [4]. Here we are using non-radial measure of DEA, i.e., SBM model with window analysis.

### 3. Slack-Based Model in DEA

Data envelopment analysis is a mathematical programming technique that measures the efficiency of a decision-making units (DMUs) relative to other similar DMUs with the simple restriction that all DMUs lie on or below the efficiency frontier [19]. There are two types of models to measure the efficiency of DMUs, one is Radial and another is non-radial. Radial models are represented by the CCR (Charnes-Cooper-Rhodes) model [4]. Basically they deal with proportional changes of inputs or outputs. As such, the CCR score reflects the proportional

maximum input (output) reduction (expansion) rate which is common to all inputs (outputs). However, in real world businesses, not all inputs (outputs) behave in the proportional way. Another drawback of the radial models is the neglect of slacks in reporting the efficiency score. So, if these slacks have an important role in evaluating managerial efficiency, the radial approaches may mislead the decision when we utilize the efficiency score as the only index for evaluating performance of DMUs. This drawback of radial models is eliminated by non-radial models.

In contrast, the non-radial SBM models put aside the assumption of proportionate changes in inputs and outputs, and deal with slacks directly. This may discard varying proportions of original inputs and outputs. The SBM models are designed to meet the following two conditions.

- (1) Units invariant: The measure should be invariant with respect to the units of data
- (2) Monotone: The measure should be monotone decreasing in each slack in input and output.

This model was introduced by [24] which directly deals with input and output slacks in DEA. Unlike the additive DEA model [5],[24] SBM gives the efficiency score between the interval of zero and one. Further,[25] presents a super-efficiency model for decision making units (DMUs) that are efficient under SBM so that efficient DMUs can be ranked. This model has been widely used to find the non-radial efficiency. [29] developed two slack-based efficiency measures for modeling environmental performance on the basis of environmental DEA technology. Of the two measures, one is a composite index with a higher discriminating power for modeling economic environmental performance, and the other can be used to estimate the impacts of environmental regulations. Since original DEA models are proposed to identify efficient performers in the most favorable scenario. For the purpose of identifying bad performers such as bankrupt firms in the most unfavorable scenario, radial worst-practice frontier DEA model has been proposed [14], they further developed HypoSBM model to distinguish the worst performers from the bad ones. Efficiency of Indian commercial banks was obtained by [20] For estimating the potential reductions and efficiency of CO<sub>2</sub> emissions for China,[8] used the slack-based measure of efficiency for potential reductions and efficiency of CO<sub>2</sub> emissions for China and its dual for estimating the marginal abatement costs of energy-related CO<sub>2</sub> emissions. A two-stage approach of slack-based model for super efficiency has been proposed by [10]. In fuzzy environment various slack-based models were proposed [21]. In network analysis a lot of research has been done with SBM measures [13], [15],[23] This model is having the structure as: Suppose we have a set of 'n' DMUs denoted by j (j=1,...,n) each having 'm' inputs and 's' outputs. Let the input and output vectors of DMU<sub>j</sub> be  $X_j = (x_{1j}, x_{2j}, \dots, x_{mj})^T$  and  $Y_j = (y_{1j}, y_{2j}, \dots, y_{sj})^T$  respectively. Then input and output matrices can be represented as

$$\mathbf{X}=(X_1, X_2, \dots, X_n) \in \mathfrak{R}^{m \times n} \text{ and } \mathbf{Y} = (Y_1, Y_2, \dots, Y_n) \in \mathfrak{R}^{s \times n}$$

The production possibility set  $\mathbf{P}$  is given by;

$$P = \{(X, Y) | X \geq \sum_{j=1}^n \lambda_j X_j, Y \leq \sum_{j=1}^n \lambda_j Y_j, \lambda \geq 0\}$$

$\lambda = (\lambda_1, \lambda_2, \dots, \lambda_n)$  is called the intensity vector. The production possibility set shows that Y can be produced by X if X is no less than the linear combination of inputs of other DMUs and Y is no greater than the linear combination of other outputs. The inequalities in the set can be transformed into equalities by introducing slacks as follows:

$$\begin{aligned} X &= \sum_{j=1}^n \lambda_j X_j + s^- \\ Y &= \sum_{j=1}^n \lambda_j Y_j - s^+ \\ s^- &\geq 0, s^+ \geq 0 \end{aligned} \tag{2}$$

Where  $\mathbf{s}^-=(s_1^-, s_2^-, \dots, s_m^-)^T$  and  $\mathbf{s}^+=(s_1^+, s_2^+, \dots, s_s^+)^T$  are input and output slacks respectively. The ratio  $(x_{io} - s_i^-)/x_{io}$  evaluates the relative reduction rate of input  $i$  and  $1/m \sum_{i=1}^m (x_{io} - s_i^-)/x_{io}$  is called mean reduction rate. Similarly  $(y_{ro} + s_r^+)/r_{ro}$  evaluates the relative expansion rate of  $r^{th}$  output and  $1/s \sum_{r=1}^s (y_{ro} + s_r^+)/y_{ro}$  is corresponding mean expansion rate, and its inverse output inefficiency. The product of these two inefficiencies can be interpreted as SBM  $\rho$ .

$$\begin{aligned} \rho_o &= \left( \frac{1}{m} \sum_{i=1}^m \frac{(x_{io} - s_i^-)}{x_{io}} \right) \left( \frac{1}{s} \sum_{r=1}^s \frac{(y_{ro} + s_r^+)}{y_{ro}} \right)^{-1} \\ &= \frac{\frac{1}{m} \sum_{i=1}^m \frac{(x_{io} - s_i^-)}{x_{io}}}{\frac{1}{s} \sum_{r=1}^s \frac{(y_{ro} + s_r^+)}{y_{ro}}} \\ &= \frac{1 - \frac{1}{m} \sum_{i=1}^m \frac{s_i^-}{x_{io}}}{1 + \frac{1}{s} \sum_{r=1}^s \frac{s_r^+}{y_{ro}}} \end{aligned} \tag{3}$$

Equation (3) is the SBM efficiency and was given by **Tone 2001** subject to the constraints given in (2). Thus the actual SBM model given by [24]

$$\begin{aligned} \min \rho_o &= \frac{1 - \frac{1}{m} \sum_{i=1}^m \frac{s_i^-}{x_{io}}}{1 + \frac{1}{s} \sum_{r=1}^s \frac{s_r^+}{y_{ro}}} \\ \text{sub to} & \\ x_{io} &= \sum_{j=1}^n \lambda_j x_{ij} + s_i^- \\ y_{ro} &= \sum_{j=1}^n \lambda_j y_{rj} - s_r^+ \\ s^- &\geq 0, s^+ \geq 0 \end{aligned} \tag{4}$$

**Definition (1):** A DMU is said to SBM efficient if its corresponding  $\rho = 0$ . This means  $s_i^- = 0, \forall i$  and  $s_r^+ = 0, \forall r$ .

The above model is in non-linear form and hence can be transformed into linear form by applying charnes cooper

transformation as:

$$\min \tau^* = t - \frac{1}{m} \sum_{i=1}^m \frac{S_i^-}{x_{io}} \tag{5}$$

sub to

$$t + \frac{1}{s} \sum_{r=1}^s \frac{S_r^+}{y_{ro}} = 1$$

$$tx_{io} = \sum_{j=1}^n \Lambda_j x_{ij} + S_i^- \quad (i = 1, \dots, m)$$

$$ty_{ro} = \sum_{j=1}^n \Lambda_j y_{rj} - S_r^+ \quad (r = 1, \dots, s)$$

$$S_i^- \geq 0(\forall i), S_r^+ \geq 0(\forall r), \Lambda_j \geq 0(\forall j)$$

Let the optimal solution of the above linear programming is  $[\tau^*, t^*, \Lambda^*, \mathbf{S}^{-*}, \mathbf{S}^{+*}]$ . Then we have optimal solution of the problem (4) as:

$$\rho^* = \tau^*, \lambda^* = \Lambda^*/t, \mathbf{s}^{-*} = \mathbf{S}^{-*}/t, \mathbf{s}^{+*} = \mathbf{S}^{+*}/t \tag{6}$$

If  $\rho^* = \tau^* = 1$  then the corresponding DMU is said to be SBM efficient, and by this condition all slacks are zero. Otherwise, it is said to be inefficient. This model is solved for each DMU in order to find its efficiency. Thus we have to solve n problems to find the efficiency of n DMUs in a given period of time. But in case of panel data we have to solve so many problems depends on the size of window and number of DMUs. The window analysis is done in the following procedure.

#### 4. Window Analysis with Slack-Based Model

In order to capture the variations of efficiency over time, [6] has proposed a technique called Window Analysis in DEA. The window analysis assesses the performance of a DMU over time by treating it as a different entity in each time-period. This method allows for tracking the performance of a unit or DMU over time and provides a better degree of freedom. If a DMU is found to be efficient in one year despite the window in which it is placed, it is likely to be considered strongly efficient compared to its peers. Suppose we have n DMU as taken in above models with same input and output matrix, but we have the data for  $T(d = 1, \dots, T)$  periods. Then  $DMU_n^d$  represents an observation n in period d with m dimensional input vector and s dimensional output vector as;

$$x_n^d = \begin{bmatrix} x_n^{1d} \\ \vdots \\ x_n^{md} \end{bmatrix}; y_n^d = \begin{bmatrix} y_n^{1d} \\ \vdots \\ y_n^{sd} \end{bmatrix}$$

If a widow starts at time period  $k(1 \leq k \leq T)$  with a window width  $w(1 \leq w \leq T - k)$  Then matrices of inputs and outputs are denoted as follows:

$$X_{kw} = \begin{bmatrix} x_1^k & x_2^k & x_3^k & \dots & x_n^k \\ x_1^{k+1} & x_2^{k+1} & x_3^{k+1} & \dots & x_n^{k+1} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ x_1^{k+w} & x_2^{k+w} & x_3^{k+w} & \dots & x_n^{k+w} \end{bmatrix}; Y_{kw} = \begin{bmatrix} y_1^k & y_2^k & y_3^k & \dots & y_n^k \\ y_1^{k+1} & y_2^{k+1} & y_3^{k+1} & \dots & y_n^{k+1} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ y_1^{k+w} & y_2^{k+w} & y_3^{k+w} & \dots & y_n^{k+w} \end{bmatrix}$$

Substituting inputs and outputs of  $DMU_n^t$  into Models will produce the results of DEA window analysis. The SBM model of DEA window problem for  $DMU_a^k$  is given by solving the following linear program:

$$\text{Min } \rho_o^k = \frac{1 - \frac{1}{m^k} \sum_{i=1}^{m^k} \frac{s_i^{(-,k)}}{x_{io}^k}}{1 + \frac{1}{s^k} \sum_{r=1}^{s^k} \frac{s_r^{(+,k)}}{y_{ro}^k}} \quad (7)$$

Sub to

$$\begin{aligned} x_{io}^k &= \sum_{j=1}^n \lambda_j^k x_{ij}^k + s_i^{(-,k)} \\ y_{ro}^k &= \sum_{j=1}^n \lambda_j^k y_{rj}^k - s_r^{(+,k)} \\ s^{(-,k)} &\geq 0, s^{(+,k)} \geq 0 \end{aligned}$$

The model (7) is slack-based model for  $k^{th}$  window in non-linear form. The same can be transformed into linear programming problem by applying Charnes cooper transformation. let us put the following transformation in model (7);

$$\begin{aligned} t &= \frac{1}{1 + \frac{1}{s^k} \sum_{r=1}^{s^k} \frac{s_r^{(+,k)}}{y_{ro}^k}} \quad (8) \\ ts_i^{(-,k)} &= S_i^{(-,k)} \\ ts_r^{(+,k)} &= S_r^{(+,k)} \\ t\lambda_j^k &= \Lambda_j^k \end{aligned}$$

By substituting these values in the model (7), a new model will be formed in terms of linear programming problem, which is as follows;

$$\text{min } \tau_t^{k*} = t - \frac{1}{m^k} \sum_{i=1}^{m^k} \frac{S_i^{k-}}{x_{io}^k} \quad (9)$$

sub to

$$\begin{aligned} t + \frac{1}{s} \sum_{r=1}^s \frac{S_r^{k+}}{y_{ro}^k} &= 1 \\ tx_{io}^k &= \sum_{j=1}^n \Lambda_j x_{ij}^k + S_i^{k-} \quad (i = 1, \dots, m) \\ ty_{ro}^k &= \sum_{j=1}^n \Lambda_j y_{rj}^k - S_r^{k+} \quad (r = 1, \dots, s) \\ S_i^{k-} &\geq 0(\forall i), S_r^{k+} \geq 0(\forall r), \Lambda_j \geq 0(\forall j) \end{aligned}$$

Model (9) is applied for every window to estimate the technical efficiency for each DMU. The windows are made on the basis of moving average method, that is one DMU is coming and one DMU leaves the system. The procedure of making windows is elaborated in the succeeding section.

## 5. Data and Selection of Variables

As it is already mentioned above that window analysis deals with cross sectional and time varying data. This cross sectional is formed in windows with a certain window length based on moving averages. As there is no theory or justification that underpins the definition of the window size, this paper utilizes a three-year window, which is consistent with the original work by [6]. Furthermore, in most often studies, window length has been taken either as three or four. If the number of years are more, then window length of four will be favorable to reduce the number of windows, otherwise three is preferable in most of cases.

To illustrate, from Table 1, the first window incorporates years 2005, 2006 and 2007. When a new period is introduced into the window, the earliest period is dropped. In window two, year 2005 will be dropped and year 2008 will be added to the window. Subsequently in window 3, years 2007, 2008 and 2009 will be assessed. The analysis is performed until window 9 analyses years 2013, 2014 and 2015. As DEA window analysis treats a DMU as different entity in each year, a three-year window with twenty eight DMUs is equivalent to 84 DMUs. Subsequently, by applying a 9, three-year window, would considerably increase the number of observations of the sample to 783, providing a greater degree of freedom.

Table 1. Windows Breakdown

window 1	2005	2006	2007								
window 2		2006	2007	2008							
window 3			2007	2008	2009						
window 4				2008	2009	2010					
window 5					2009	2010	2011				
window 6						2010	2011	2012			
window 7							2011	2012	2013		
window 8								2012	2013	2014	
window 9									2013	2014	2015

The data set used in this paper was obtained from the database **Centre for Monitoring Indian Economy (CMIE)** and the annual reports of Indian cement companies for the period 11 years from 2005C2015. The descriptive statistics of the variables (three inputs and one output) are given in the Table 2

Table 2. DESCRIPTIVE STATISTICS OF VARIABLES

	Power, Fuel & Water Charges	raw Materials Stores & Spares	Compensation to Employees	Miscellaneous Expenditure	Net Sales
Mean	5091.39	4187.49	139.73	1735.77	26646.75
Median	2472.90	1910.15	494.05	485.60	11301.55
Max	46875.60	34941.10	12248.60	23118.20	260210.70
Min	8.70	4.10	22.80	5.50	0.30
St. Dev.	6694.27	5689.11	1926.38	207.88	34092.18

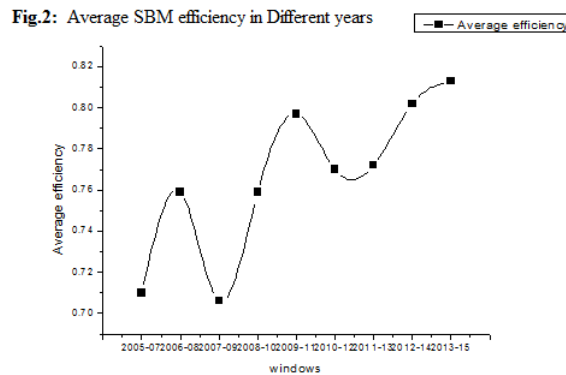
In this paper, the data set comprises of 28 cement companies. As we have reliable data extracted directly from annual reports, we eliminate the risk that incomplete or biased data may distort the estimation results. In order to conduct SBM DEA window analysis estimation, inputs and outputs need to be defined. Here we have employed four inputs as: 1) Power, fuel and water charges 2) Raw materials, stores and spares 3) Compensation to employees 4) Miscellaneous expenditure and the only output as Net sales. Here we adopted DEA window analysis SBM (slack based model C non-radial) models that can evaluate the overall efficiency of decision-making units for the period from 2005-15. For empirical analysis we used DEA solver a add-on option in Microsoft excel where we solved as many as linear problem as number of DMUs in each window. The results of the SMB



Table 3. EFFICIENCY OF CEMENT COMPANIES IN DIFFERENT WINDOWS

DMUs	2005 -2007	2006 -2008	2007 -2009	2008 -2010	2009 -2011	2010 -2012	2011 -2013	2012 -2014	2013 -2015
Ultratech	0.710	0.825	0.743	0.789	0.787	0.841	0.837	0.859	1.000
A C C Ltd.	0.677	0.726	0.668	0.726	0.746	0.726	0.711	0.718	0.739
Ambuja cem.	0.727	0.763	0.679	0.720	0.756	0.738	0.751	0.749	0.768
Shree cem.	0.832	0.919	0.710	0.851	0.884	0.857	0.784	0.919	0.827
Prism cem.	0.707	0.698	0.651	0.778	0.832	0.820	0.830	0.873	1.000
India Cem	0.622	0.752	0.763	0.677	0.633	0.597	0.634	0.752	0.597
Ramco Cem	1.000	1.000	0.734	0.782	0.965	0.938	0.874	0.890	0.958
J K Cem	0.645	0.673	0.655	0.744	0.708	0.689	0.696	0.727	0.699
Birla Corp	0.496	0.533	0.536	0.615	0.718	0.660	0.617	0.695	0.590
OCL India	1.000	1.000	0.638	0.686	0.734	0.716	0.702	0.717	0.816
JK Lakshmi	0.529	0.560	0.537	0.607	0.643	0.661	0.727	0.794	0.801
Heidelberg	0.507	0.570	0.479	0.580	0.784	0.764	0.691	0.781	0.706
Mangalam	0.609	0.642	0.604	0.698	0.767	0.706	0.698	0.742	0.645
K C P	0.472	0.530	0.511	0.487	0.471	0.524	0.621	0.664	0.588
Saurashtra	0.454	0.488	0.498	0.589	0.654	0.682	0.731	0.722	0.701
Shree Dig.	0.523	0.545	0.481	0.549	0.678	0.766	0.841	0.680	0.553
Gujarat Sid.	1.000	1.000	1.000	1.000	1.000	1.000	0.695	0.619	0.599
Andhra Cem	0.499	0.538	0.544	0.574	0.632	0.487	0.443	1.000	0.601
Barak Valley	0.622	0.644	0.537	0.566	0.621	0.570	0.545	0.520	0.541
Panyam Cem	0.562	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Rain Cem	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Jaiprakash	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Chettinad	0.697	0.756	0.748	0.846	0.864	0.747	0.768	0.755	1.000
Prism Cem	0.707	0.698	0.651	0.778	0.832	0.820	0.830	0.863	1.000
Sanghi Indus.	1.000	0.869	0.840	1.000	1.000	1.000	1.000	1.000	1.000
Binani Cem	0.813	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Century Text.	0.480	0.537	0.506	0.533	0.545	0.533	0.540	0.535	0.565
MyHome ind.	1.000	1.000	1.000	1.000	1.000	0.917	1.000	1.000	1.000
<b>Mean</b>	<b>0.710</b>	<b>0.759</b>	<b>0.706</b>	<b>0.759</b>	<b>0.797</b>	<b>0.770</b>	<b>0.772</b>	<b>0.802</b>	<b>0.813</b>

DEA efficiency scores during the period 2005-2015 are presented in Table (2). we have taken the window width of three years because [7] found that  $w=3$  or  $4$  tended to yield the best balance of informativeness and stability of the efficiency scores. In order to be sure that the results will be credible, a narrow window width must be used. Therefore, a 3 year window has been chosen in this paper. During the period 2005-15 the average SBM efficiency calculated ranges from 71% to 81%. This average efficiency shows the frontier shift in various windows. It indicated how technology has changed during the given period. It can be seen from the table that technology is increasing from initial period to the end except the two periods 2007-09 and 2010-12. This development shows that Indian cement companies are on average considered to be efficient, with only marginal changes over time. The results show that the average efficiency was highest in 2013-15 and lowest in 2007-09. Two companies which were efficient in all windows were Rain cements and Jaiprakash cements.



The figure (2) shows the trend of average SBM efficiencies during the given period. It can be seen from the figure(2) that on an average there is a upward(positive) direction of frontier. The highest efficiency is in the last window. After solving linear problems we find values of slacks mostly of input slacks. It was found that most of cases there was so much slacks in inputs especially raw materials and power,fuel and water. Theses are the main causes which are responsible for the inefficiency of the firms.

## 6. Conclusion

The aim of this paper is to estimate the efficiency of the Indian cement industry employing the Data Envelopment Analysis (DEA) window analysis approach during the period 2005-2015. It is the first application of the DEA window analysis approach on the Indian cement Industry. The research was based on unbalanced panel data for the period from 2005 to 2015. In this study we applied the DEA window analysis based on a non-radial slack-based model to measure relative efficiency of indian cement companies. We found two companies i.e., Rain cements and Jaiprakash cements which were efficient in all windows. On contrary, many cement companies were found efficient in one window and inefficient in other. The mean of efficiencies given in last row of table (2) shows the frontier displacement, to see the technological change in all the years. The results of the paper is that whereas during the period 2005-2006 the average efficiency was increasing, then in 2007-09 the average efficiency decreased and after that it began to increase till 2009-11, and then again fell down little bit in 2010-12, after that it starts increasing till end. For all cement companies it is important to examine the strategic plan for improving the operations, better use of capacities of plants and search tools to improve the service of these cement plants. Progress is made in the measurement of cement company efficiency in relation to port productive activities. In our study there were positive slacks in both inputs and outputs, but the slacks were more in inputs as compared to outputs. Thus in order to increase their productivity and efficiency they have reduce their inputs considerably.

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