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Technological Progress, Scale Effect and Total Factor Productivity Growth in Indian Cement Industry: Panel Estimation of Stochastic Production Frontier

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TECHNOLOGICAL PROGRESS, SCALE EFFECT AND TOTAL FACTOR PRODUCTIVITY GROWTH IN INDIAN CEMENT INDUSTRY: PANEL ESTIMATION OF STOCHASTIC PRODUCTION FRONTIER

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

Abstract

The economic policy reform in respect of Indian cement industry, during the early 80's, resulted in a phenomenal growth of this sector and the industry has, in fact, become the second largest in the world. However, this growth has been associated with a greater use of energy and other resources, resulting in severe environmental degradation. Further development of this industry, without increasing energy demand and thereby reducing emission and waste, would require increased productivity. This paper estimates Total Factor Productivity (TFP) growth in Indian cement industry during the period 1989-90 to 2006-07 using company level data and applying Stochastic Frontier Approach. TFP growth is decomposed into technical progress (TP), technical efficiency change (TEC) and changes in scale component (SC) with a view to gaining some insights into the sources of productivity growth of this industry in the post reform era. Empirical results show that TFP growth is mainly driven by SC and TP and not by TEC since TE is time invariant in nature. In the light of empirical results, the policy implication is that an industrial policy of exploiting the existing economies of scale is required to be implemented; and to boost the growth of this sector; priority should be given to enhance firms' capability of catching-up by adopting efficiency oriented action plan.

Introduction

Indian cement industry witnessed an unprecedented growth as a sequel to government's liberalization policy initiated in the form of partial decontrol in 1982, culminated in total decontrol in 1989. However, this huge growth in cement production has been associated with a price to pay in terms of higher utilization of energy. Among the energy intensive industries in India, cement industry has the highest energy intensity with 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 very large increase in energy input, especially in the form of coal combustion.

This has resulted in severe environmental problems in the coal mining regions and around the cement producing plants. In addition, India's annual emission of green house gases from the cement industry increased from 7.32 mt in 1993 to 16.73 mt in 2003 and its share in total 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 since effected many policy changes over the past 25 years or so to increase the energy efficiency of the firms and thereby reduce the CO_2 emission, with particular emphasis on energy-

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intensive heavy industries such as the cement industry.[1] As a result, the energy intensity (measured by the ratio of energy consumption and gross value added) of this industry declined from 0.93 in 1993-94 to 0.89 in 2006-07. This decline in energy intensity can be attributed to the energy efficiency policies introduced by the government over this period.

However, cement production is a complex procedure, involving several stages wit h multiple inputs, and energy being only one of the many inputs. Besides the energy efficiency policies, which addressed the energy use directly, many other factors could also have affected the energy intensity of this sector. Sine the early 1980s, when the partial decontrol policy was introduced in this sector, enterprises have been given greater auto nomy, management skills have improved and the industry has become more market oriented. More advanced production technologies have been adopted and existing equipment s have been upgraded. Scale of operation by the firms has been increased significantly with a change in composition of output also. All these factors could have affected the overall productive efficiency of the cement companies and hence the energy intensity of the industry. (For example, Hogan and Jorgenson have identified productivity growth as an important factor reducing energy use and hence CO_2 emission in the US.) If India wants to further develop this industry without increasing energy intensity and aggravating the present severe environmental problems, it is necessary to substantially increase productivity. The aim of this paper is to examine whether the growth of this sector, during the study period, has been achieved through a growth in TFP or this growth has been achieved by large increase in input uses. To do this, we have estimated and examined the trends in TFP growth of this industry over the period 1989-90 to 2006-07 using firm level data. To identify the sources of productivity growth, we have decomposed the TFP growth into technological change, technical efficiency change and scale effects. Further, the direction of technological change has also been taken into consideration to examine whether technological progress in this sector is energy using or energy saving in nature.

We have examined the efficiency of the firms using the method of analysis originally proposed by Farrell (1957). The Farrell efficiency measurement consists of two components: technical efficiency, i.e. ability of a production unit to produce maximum attainable output from a given level of input bundle (output oriented efficiency) or to produce a given level of output with a minimum possible input bundle (input oriented efficiency); and the allocative efficiency which refers to the ability of the firm to combine inputs and outputs in optimal proportions, given their respective prices and production technology (see Coelli et al., 1998, pp.134-140, and lovell,1993,p.40, for detailed discussions). We focused on technical efficiency, since it gives a measure of the maximum possible expansion of the output for a given level of input factor and technology.

Technical efficiency, as being a static concept that compares the performance of a particular firm in a particular time period with the performance of the best performing firms in the group in that particular period, can not take into account the overtime improvement in performance including improvements in the productivity of the best performers. So we have also estimated the productivity growth of the firms. Now, productivity can be measured either by partial productivity, ratio of output to a particular input, or by total factor productivity, ratio of output to weighted sum of all inputs. Partial productivity may some time give a distorted picture of productivity growth. For example, if energy requirement per unit of output decreases then energy productivity will improve. But this reduction in energy requirement may be achieved by larger use of labor or capital. So we have used the notion of total factor productivity, a measure of productivity growth that recognizes that all inputs are scarce and that the desired pr oductivity growth is that growth which comes from the combined savings over all inputs, not just one input. Total factor productivity has been decomposed using stochastic production frontier originally proposed by Nishimizu and Page (1982). We have followed the approach of Kumbhakar and Lovell (2000) for decomposing total factor productivity growth.

The paper organizes as follows. A brief overview of the status of the cement industry in terms of output and employment, production technology and product structure is discussed in the following section. Next, we have presented a brief review of the studies related to productivity growth in the context of Indian cement industry. The next section outlines methodology which includes decomposition of TFP and presents the functional form of the estimation model. Following this, data description and measurement framework used for productivity analysis and quantitative results have been presented. The last section contains some concluding remarks.

The cement industry in India

Output and employment

India's cement industry has been witnessing a phenomenal growth since early 1980s, when the country adopted price decontrol policy for this industry. Table 1 outlines the enormous growth both in installed capacity and production in Indian cement industry. Commencing with a capacity of 3.28 million tones in 1950-51, cement industry surged to a capacity of 177.83 million tones in 2006-07. Similarly, production of cement increased from 2.95 million tones in 1950-51 to 161.66 million tones in 2006-07. Capacity utilization, which was 90% during 1950-51, gradually decreased to 67% in 1980-81. It however, took a reverse turn in the eighties and started increasing slowly.

Table 1: Changes in installed capacity, production and capacity utilization (1950-2006)

Year	Installed capacity (million tones)	Production (million tones)	Capacity utilization (%)
1950-51	3.28	2.95	90
1960-61	9.30	7.97	86
1970-71	17.61	14.36	82
1980-81	27.92	18.66	67
1984-85	42.50	30.10	71
1989-90	60.00	45.30	76
1991-92	65.00	53.00	81
1996-97	105.00	76.00	72
2000-01	119.30	98.00	82
2006-07	177.83	161.66	91

Source: CMA, Cement Statistics, New Delhi, For different years

According to the Cement Manufacturing Association (CMA), this industry at present employs a large number of work force which is over 1.35 lakh persons and supports another 12 lakh persons engaged indirectly.

Production technology[2]

In cement production, raw materials preparation involves primary and secondary crushing of the quarried material, drying the material (for use in the dry process) or undertaking a further raw grinding through either wet or dry process, and blending the materials. Clinker production is the most energy-intensive step, accounting for about 80% of the energy used in cement production. Produced by burning a mixture of materials, mainly limestone, silicon oxides, aluminum, and iron oxides, clinker is made by one of the two production processes: wet or dry; these terms refer to the grinding processes although other configurations and mixed forms (semi-wet, semi dry) exist for both types. The dry process is modern and more energy-efficient as compared to the wet process, and the semi-wet is somewhat more energy efficient than the semi-dry process. The semi-dry process has never played an important role in Indian cement production and accounts for less than 0.2% of total production. In 1960, around 94% of the cement plants in India were dependant on wet process kilns. However, these kilns have been phased out over the last 46 years; and in 2006-07, 96.3% of the kilns were based on dry process, 3% on wet, and only 1% on semi dry process. Dry process kilns are typically larger, with capacities in India ranging from 300-8000 tonnes per day or tpd (average of 2880tpd). While capacities in semi-dry kilns range from 600-1200 tpd (average 521 tpd), and capacities in wet process kilns range from 200-750 tpd (average 425 tpd).

Over the last decade, increased preference is being given to the energy efficient dry process so as to achieve cost efficiency in a competitive market. Moreover, since the initiation of the decontrol process, many manufacturers have switched over from the wet technology to the dry one by making suitable modifications in their plants.

Product structure

The types of cement in India have increased over the years with advancements in research and development, and technology. By a fair estimate, there are around 11 different types of cement being produced in India. Some of the varieties of cement produced in India are: Clinker Cement, Ordinary Portland Cement, Portland Blast furnace Slag Cement, Portland Pozzolana Cement, Rapid Hardening Portland Cement, Oil Well Cement, White Cement and Sulphate Resisting Portland Cement. Among the different kinds of cement produced in India, Portland Pozzolana Cement, Ordinary Portland Cement, and Portland Blast Furnace Slag Cement are the most important ones because they account for around 99% of the total cement production in the country. Table 2 outlines the changes in the variety of cement production in India.

Table 2: Trends in variety of cement production (million tones): 1995/96 to 2004/05

Year	Ordinary Portland cement	%	Portland Pozzolana cement	%	Portland blast furnace slag cement	%	Others	%	Total
1995/96	45.04	70.00	11.77	18.00	7.10	11.00	0.62	1.00	64.53
1996/97	48.46	70.00	13.60	19.00	7.33	10.00	0.59	1.00	69.98
1997/98	54.30	70.76	14.48	18.87	7.45	9.71	0.51	0.66	76.74
1998/99	57.40	70.28	15.57	19.07	8.21	10.05	0.49	0.60	81.67
1999/00	62.76	66.62	21.30	22.61	9.39	9.97	0.76	0.80	94.21
2000/01	58.06	62.02	24.50	26.17	10.34	11.05	0.71	0.76	93.61
2001/02	57.68	56.32	32.29	31.53	11.89	11.61	0.54	0.54	102.40
2002/03	56.05	50.34	43.08	38.69	11.63	10.44	0.59	0.53	111.35
2003/04	53.51	45.54	52.12	44.36	11.26	9.58	0.61	0.53	117.50
2004/05	55.97	43.88	60.23	47.21	10.73	8.41	0.64	0.50	127.57

Source: CMA, Cement Statistics 2005, New Delhi

From Table 2, it is clear that, percentage share of Ordinary Portland Cement in total cement production decreased continuously after 1998-99 while the share of Portland Pozzolana Cement increased from 18% in 1995-96 to 47.21% in 2004-05.

Previous Studies

Productivity growth in the cement industry has been studied extensively and systematically by many researchers. There are studies where the focus is on the cement industry per se and also those where the industry has been studied as part of a group of industries.

Gupta (1973), in a three input (capital, labor and raw material) framework and using modified Kendrik index, estimated total factor productivity growth (TFPG) of Indian cement industry during the period 1946-65. His study shows an annual – 1.06 per cent growth in TFPG. Mahopatra (1970) studied the industry for the period 1949-64 using Solow index to estimate TFFG and arrived at 1.80 per cent annual growth in TFPG. One interesting aspect of his study is that he related output of a given period to the capital stock of the previous period for considering the lag between capital installed and production of output by the installed capital. This is quite justified because installed capital does require some time before starting production. Sawhney (1967) and Sinha and Sawhney (1970) arrived at more or less the same rates of TFPG because of the similarity of methods and time period covered. Both the studies used Kendrick index to estimate TFPG and arrived at 1.90 per cent and 1.70 per cent annual TFPG respectively. Mehta's (1980) study covered the period 1953-1964 and estimated annual TFPG as – 5.40 per cent by using Solow index. Arya (1981) covered the period 1951-70 and used Solow index to estimate TFPG. His study shows a negligible amount of TFPG which is 0.25 per cent. Acharya and Nair (1978) also came up with the same rate of annual TFPG as compared to Arya. Goldar's (1986) study estimates for 1960-70 are consistent with that of CSO (1981) for the comparable period. Both the studies used Kendrick index. Goldar's study reported 0.50 per cent annual growth rate whereas CSO reported 1.62 per cent, - 0.30 per cent and 2.99 per cent for the periods 1960-77, 1960-71 and 1969-77 respectively. Arora's (1987) study reported – 1.96 per cent annual growth in TFP. Pradhan's (1998) study reported 1.71 per cent annual growth in TFP. Both Arora and Pradhan used Translog index for estimating TFPG.[3]

The estimates of these studies spread across in a wide range. The variations arise mainly because of differences in data source used, measurement of variables, methodology adopted and time period covered by different studies. In spite of these differences, it appears that the most likely long run rate of growth of total factor productivity for the years 1945 to 1985 can be restricted to the range -0.5 to 0.5 per cent per annum. In the recent year, Sharma (2007) estimated TFPG for the period 1989-2005 with a view to studying the impact of liberalization on productivity growth. Under the growth accounting approach, Divisia Tornquist index has been used to construct the Total Factor Productivity Growth (TFPG) index and the Partial Productivity Indices (PPIs) of four factors of production viz., capital, labor, material and energy. The findings reveal that the Indian cement industry has experienced a sharp decline in the TFP index over a study period from 1989 to 2005.

Reviewing the earlier studies related to productivity growth in Indian cement industry, we can come out with certain observations regarding the limitations of the previous studies. *First,* almost all the studies have used Index Number Approach in estimating TFP growth. In this approach the observed growth in output is sought be explained in terms of growth in factor inputs. The unexplained or the residual is attributed to growth in productivity of factors (Mongia et al., 1998). Validity of this residual approach depends on the assumption that all the firms operate on the production frontier with 100% efficiency; Further under the residual approach, technical progress is usually considered to be the unique source of TFP growth. But recent developments in the TFP estimation acknowledge that along with technical progress, changes in technical efficiency- the gap between frontier technology and a firm's actual production - can also contribute to productivity growth. So in our present study we have used stochastic frontier models which assume that firms may not be able to fully utilize the existing technology because of various non-price and organizational factors that may lead to inevitable technical inefficiencies in production. *Secondly,* earlier studies have not examined the role of scale components - adjustments towards optimum production scale - in productivity growth. Empirical studies show that scale effects may also contribute, to some extent, in TFP growth (see Kim et.al, 2001 and Sharma et al., 2004). To the best of our knowledge, this is the first study which considers the role of scale effect in productivity growth in the context of Indian manufacturing. *Thirdly,* role of energy input in the energy intensive cement industry, has not been studied exhaustively. Because of our special interest in energy use, and also because of the important role of energy in the cement industry, we have included energy as a separate input factor in our study of productivity growth.

Methodology

Decomposition of TFP

In the present study, stochastic frontier approach has been adopted to decompose TFP. Now, TFP may arise, as it is mentioned earlier, either due to technical progress or due to improvement in technical efficiency. The decomposition of TFP can be introduced in the production function.

Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977) independently proposed the stochastic frontier production function defined by

$$y_{it} = f\left(x_{it}, b, t\right) \exp\left(v_{it}\right) \exp\left(-u_{it}\right), \tag{1}$$

where y_{it} is the maximum possible output produced by i th firm (i= 1, 2,.......,N) in the t th period (t=1,.........,T); with $f(.)$ being the production frontier; x_{it} being the input vector used by i th firm ; b being the vector of technology parameter ; t being the time trend index that serves as proxy for technical change; and $u_{it} \geq 0$ is the output oriented technical inefficiency. The random error, v_{it}, accounts for measurement error and all other random factors outside the control of this firm, such as weather, strikes, luck, etc., that are likely to affect its maximum possible output, together with the combined effects of unspecified input variables in the production function. It can be noted from equation (1) that technical inefficiency in equation (1) varies over time. The production frontier, $f(.)$, is totally differentiated with respect to time to get

$$\frac{d \ln f\left(x_{it}, t\right)}{dt} = \frac{\partial \ln f\left(x_{it}, t\right)}{\partial t} + \sum_j \frac{\partial \ln f\left(x_{it}, t\right)}{\partial x_j} \frac{dx_j}{dt} \tag{2}$$

The first and second terms on the right-hand side of equation (2) measure the change in frontier output caused by TP and by change in input use respectively. From the output elasticity of input j, $e_j = \frac{\partial f\left(x_{it}, t\right)}{\partial \ln x_j}$, the second term can be expressed as $\sum_j e_j \dot{x}_j$, where a dot over a variable indicates its rate of change. Thus, equation (2) can be written as

$$\frac{d \ln f\left(x_{it}, t\right)}{dt} = \text{TP} + \sum_j e_j \dot{x}_j \tag{3}$$

Totally differentiating the logarithm of y in equation (1) with respect to time and using equation (3), the change in production can be represented as

$$\dot{y}_{it} = \frac{d \ln f(x_{it})}{dt} - \frac{du}{dt} = TP + \sum e_j \dot{x}_j - \frac{du}{dt} \tag{4}$$

The overall productivity change is not only affected by TP and changes in input use, but also by changes in technical inefficiency. TP is positive (negative) if the exogenous technical change shifts the production frontier upward (downward), for a given level of inputs. If $\frac{du}{dt}$ is negative (positive), TE improves (deteriorates) over time, and $-\frac{du}{dt}$ can be interpreted as the rate at which an inefficient producer catches up with the production frontier.

To examine the effect of TP and a change in efficiency on TFP growth, $\dot{TFP}$ is defined as output growth unexplained by input growth:

$$\dot{TFP} = \dot{y} - \sum_j S_j \dot{x}_j , \tag{5}$$

where S_j is input j's share in production cost.

By substituting equation (4) into equation (5), equation (5) can be rewritten as

$$\begin{aligned} \dot{TFP} &= \mathrm{TP} - \frac{du}{dt} + \sum_j (e_j - S_j)\dot{x}_j \\ &= \mathrm{TP} - \frac{du}{dt} + (\mathrm{RTS} - 1)\sum_j l_j \dot{x}_j + \sum (l_j - S_j)\dot{x}_j , \end{aligned} \tag{6}$$

where RTS $\left(= \sum_j e_j \right)$ denotes the measurement of returns to scale, and $l_j = \frac{f_j x_j}{\sum_l f_l x_l} = \frac{e_j}{\sum_l e_l} = \frac{e_j}{RTS}$. The last component in equation (6) measures inefficiency in resource allocation resulting from the deviations of input prices from the value of their marginal product. Thus, in equation (6), TFP growth can be decomposed into TP, the technical efficiency change $\left(-\frac{du}{dt} \right)$, scale components SC= $(RTS - 1)\sum_j l_j \dot{x}_j$, and the allocative efficiency change denoted by $\sum (l_j - S_j)\dot{x}_j$. In the present study, TFP growth is not adjusted for allocative efficiency change. The decomposition formula in equation (6) is drawn from Kumbhakar and Lovell (2000).

Functional Form

The most commonly used tool of analysis for measuring technical efficiency is the frontier production function. We will consider the time-varying stochastic production frontier, originally proposed by Aigner, Lovell and Schmidt (1977) in translog form as:

$$\ln y_{it} = a_0 + \sum_j a_j \ln x_{jit} + a_t t + \frac{1}{2}\sum_j \sum_l b_{jl} \ln x_{jit} \ln x_{lit} + \frac{1}{2} b_{tt} t^2 + \sum_j t b_{tj} \ln x_{jit}$$

$$+ v_{it} - u_{it} \qquad (7)$$

The efficiency error, u_{it} represents production loss due to firm-specific technical inefficiency; thus it is always greater than or equal to zero$(u \geq 0)$, and it is assumed to be independent of the statistical error, v_{it}, which is assumed to be independently and identically distributed as N$\left(0, s_v^2\right)$.

The translog frontier production function as specified in equation (7) is rewritten for four inputs capital, labor, material and energy in the following form,

$$\ln y_{it} = a_0 + a_l \ln L_{it} + a_k \ln K_{it} + a_m \ln M_{it} + a_e \ln E_{it} + a_t t + \frac{1}{2} b_{ll} (\ln L_{it})^2 + \frac{1}{2} b_{kk} (\ln K_{it})^2$$

$$+ \frac{1}{2} b_{mm} (\ln M_{it})^2 + \frac{1}{2} b_{ee} (\ln E_{it})^2 + b_{lk} (\ln L_{it})(\ln K_{it}) + b_{km} (\ln K_{it})(\ln M_{it})$$

$$+ \quad b_{lm} (\ln L_{it})(\ln M_{it}) + b_{le} (\ln L_{it})(\ln E_{it}) + b_{ke} (\ln K_{it})(\ln E_{it}) + b_{me} (\ln M_{it})(\ln E_{it})$$

$$+ b_{tl} (\ln L_{it}) t + b_{tk} (\ln K_{it}) t + b_{tm} (\ln M_{it}) t + b_{te} (\ln E_{it}) + \frac{1}{2} b_{tt} t^2 + (v_{it} - u_{it}) \qquad (8)$$

Where y_{it} is the gross value of output, K, L, M and E are the inputs for capital, labor, material and energy respectively. The above specification allows for estimating both technical progress and time varying technical efficiency. The above translog parameterization of stochastic frontier model allows for non-neutral technical progress (TP). Technical progress will be neutral if all b_{tj}'s are equal to zero and the production function will be reduced to Cobb-Douglas function with neutral TP if all the b s are equal to zero.

The distribution of technical inefficiency effects, u_{it}, is taken to be non-negative truncation of the normal distribution N $\left(m, s_u^{\,2}\right)$, modeled, following (Battese & Coelli 1992, Greene 1997: pp119) to be the product of an exponential function of time as

$$u_{it} = h_t u_i = \exp[-h(t-T)]u_i \text{ , i= 1,..., N; t = 1, ..., T} \qquad (9)$$

Here the unknown parameter h represents the rate of change in technical inefficiency, and the non-negative random variable u_i, is the technical inefficiency effect for the i th production unit in the last year of the data set. That is, the technical inefficiency effects in earlier periods are deterministic exponential function of the inefficiency effects for the corresponding forms in the final period$(i.e. u_{it} = u_i,)$ given the data for the i th production unit are available in the final period. So the production unit with a positive h is likely to improve its level of efficiency over time and vice-versa. A value of h =0 implies technical inefficiency is time invariant. Since the estimates of technical efficiency are sensitive to the choice of distributional assumption, we consider truncated normal distribution for general specifications of one - sided error u_{it}, and half - normal distribution can be tested by LR test.

Technical efficiency of unit i at time t (TE_{it}), defined as the ratio of the actual output to the potential output determined by the production frontier, can be written as follows,

$$(TE_{it}) = \exp\left(-u_{it}\right) \tag{10}$$

and technical efficiency change is the change in TE, and the rate of technical progress (TP_{it}) is defined by,

$$TP_{it} = \frac{\partial \ln\left(y_{it}\right)}{\partial t} = a_t + b_{tt}t + b_{tl}\left(\ln L_{it}\right) + b_{tk}\left(\ln K_{it}\right) + b_{tm}\left(\ln M_{it}\right) + b_{te}\left(\ln E_{it}\right) \tag{11}$$

The elasticity of output with respect to the j th input is defined as ,

$$e_j = \frac{\partial \ln f\left(x_{it}, t\right)}{\partial \ln x_j} = \sum_{l \neq j} b_{jl} \ln x_l + b_{jj} \ln x_j + b_{tj} t, \quad \text{j,l= L, K} \tag{12}$$

DATA SOURCES, MEASUREMENT OF VARIABLES AND PERIOD OF THE STUDY

The main data source for the study is PROWESS created by Centre for Monitoring Indian Economy (CMIE). PROWESS provides all kinds of financial information to the companies from their annual balance sheet. PROWESS data on value of output, gross value added, wages and salaries, expenses for power and fuel, 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. 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 function, we have included material and energy variables which are intermediate inputs. Moreover, gross value added is negative for a huge number of firms, reducing the number of sample to an unacceptable level in the logarithmic model that fitted best. 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 considered as expenses for material and expenses for power and fuel respectively. Material input is deflated by the price index of non-metallic mineral product while 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 considered gross fixed asset in place of net fixed asset because depreciation charges in the Indian industries are known to be highly arbitrary, fixed by income tax authorities hardly representing actual consumption. The standard Perpetual Inventory Method (PIM), suggested by Balakrishnan, Pushpangadan and Babu (2000), is used to construct the capital stock with 1995-96 as the benchmark (for a detail of PIM, see appendices).

The period chosen for the analysis in the present study is 1989-90 to 2006-2007 and unbalanced panel of 70 firms has been constructed for the study. In each year the selected firms produced more than 75% of the industry output. So our sample of firms may be considered as representative for the industry. 1989 is the period when government introduced complete decontrol policy for the cement industry. So the study would reveal whether the decontrol policy has enhanced the productivity of Indian cement industry in the subsequent periods.

Table 3: Summary statistics for variables used in the estimation

Variables	Mean	Std. Dev.	Minimum	Maximum
Output	2.8609	5.4299	0.0011	43.5894
Capital	4.3628	7.8269	0.0052	57.2147
Energy	0.4851	0.7263	0.0001	3.8753
Labor	0.0639	0.1261	0.00002	0.7791
Material	0.5120	1.2950	0.0007	10.9856

Note s:

1. All values are in Rs. crore
2. All the above variab les are transformed into logarithmic values and then used in the actual estimation

EMPIRICAL RESULTS

The present study has estimated the trends of TFP growth, technical efficiency change and direction of technological progress in the context of Indian Cement companies during the period 1989-90 to 2006-07. The maximum likelihood estimates for the parameters of the stochastic frontier model, defined by equation (8), are obtained using the program FRONTIER 4.1, in which the variance parameters are expressed in terms of $g = \frac{s_u^2}{s_s^2}$ and $s_s^2 = s_u^2 + s_v^2$ (see Coelli, 1996).

Following Battese and Coelli (1992), the unrestricted model 1.0 and seven restricted models have been estimated in order to choose appropriate functional form to check the validity of the modeling of the technical inefficiency effects and technical change captured by a time trend. Model 1.0, involving all the parameters being estimated, is the stochastic translog frontier production function in which the technical inefficiency effects, u_{it}, have the time-varying structure and follow truncated normal distribution. Model 1.1 is the stochastic Cobb-Douglas frontier production function with Hicks-neutral technical change and time-varying technical inefficiency effects. Model 1.2 is the stochastic translog frontier production function with no technical change and time-varying inefficiency effects. Model 1.3 is the stochastic translog frontier production function with Hicks-neutral technical change and time-varying inefficiency effects. Model 1.4 is the traditional specification of translog production function in which inefficiency effects are absent, i.e. production is assumed to be fully efficient. Model 1.5 is a special case of model 1.0 in which u_{it} follows half-normal distribution. Model 1.6 is also a special case of model 1.0 in which u_{it} is time - invariant considered by Battese and Coelli (1989) and Battese, Coelli & Colby (1989). Model 1.7 is another special case of model 1.0 in which u_{it} is time-invariant and it follows half-normal distribution, i.e. model 1.7 is a combination of both model 1.5 and model 1.6.

Table 4 shows the estimates of various (frontier) production functions while Table 5 reports the test statistics for the different null hypotheses. The null hypotheses are tested using likelihood ratio (LR) tests. The likelihood-ratio test statistic is $l = -2[L(H_0) - L(H_1)]$, where $L(H_0)$ and $L(H_1)$ are the values of the log-likelihood function under the null and general hypotheses respectively. If the null hypothesis is true, then l has approximately a Chi-square (or mixed Chi-square) distribution with degrees of freedom equal to the number of restrictions. If the null hypothesis includes $g = 0$, then the asymptotic distribution is a mixed Chi-square distribution. Given the specifications of translog frontier production and the results of statistical tests on the estimated parameters, the preferred model is chosen as model 1.7. It can be seen from the table that most of the coefficients obtained in model 1.7 are significant at 1 per cent level.

Direction of technical change

An implication of the non-fulfillment of Hicks-neutrality test is that technical change in Indian Cement industry involves a technical bias. It can be seen from Table 4 that, the coefficients of $t(\ln K)$, $t(\ln L)$ and $t(\ln E)$ are positive while that of $t(\ln M)$ is negative which implies that technological progress in Indian Cement industry involves capital, labor and energy using but material saving bias. Here we are using the definition of the direction of technical change given by Berndt, 1990. Technological change will be input i- saving (input i-using) if the proportional savings on i-th input is greater than (less than) the average proportional savings over all inputs. Technical progress is said to be input i- neutral if the proportional savings on i-th input just equals the average proportional savings over all inputs (Berndt, 1990). So according to this definition, an energy using technical change does not imply that energy per unit of output is increasing due to this energy using technological change, rather it implies that proportional saving in energy is less than average proportional savings over all inputs. The direction of technical changes for all the inputs in our study corroborates the study by Roy, et al. (1999) except for labor. Technical change in our study involves a labor using bias while that is labor saving in the study by Roy, et al. (1999). One possible explanation for labor using technical change in our study may be as follows: during the period of our study, we found that most of the cement companies were going for technological up-gradation for which skilled labor in the form of engineers and trained personnel are required. So firms were found spending more on human capital in the form of higher salaries. Since we have measured labor input in terms of wages and salaries, this higher spending may lead to labor using technical change.

Table 4: PANEL ESTIMATION OF STOCHASTIC PRODUCTION FRONTIER AND TECHNICAL EFFICIENCY MODEL

Variable	Model 1.0	Model 1.1	Model 1.2	Model 1.3	Model 1.4	Model 1.5	Model 1.6	Model 1.7
Constant	0.1487 (*1.22*)	0.5492*** (5.39)	0.6305*** (11.43)	0.2615** (2.34)	-0.3019*** (-5.73)	0.0728 (*0.893*)	0.0883 (*0.822*)	0.0472 (0.659)
$\ln K$	0.0786* (*1.44*)	0.0132 (0.5400)	0.1264*** (4.66)	0.1504*** (5.56)	0.1203** (2.25)	0.0750* (*1.40*)	0.0791* (*1.45*)	0.0758* (1.39)
$\ln E$	0.4697*** (*10.65*)	0.5171*** (26.42)	0.4845*** (15.27)	0.4707*** (14.41)	0.4913*** (10.72)	0.4726*** (*10.76*)	0.4695*** (*10.60*)	0.4820*** (10.66)
$\ln L$	0.0962 (*2.11*)	0.1820 (6.37)	0.1869*** (4.83)	0.1823 (5.02)	0.0141 (0.322)	0.0903 (*1.97*)	0.0936 (*2.06*)	0.0896* (1.94)
$\ln M$	0.3699*** (*12.22*)	0.3173*** (26.65)	0.2683*** (14.23)	0.2563*** (14.09)	0.4017*** (12.63)	0.3732*** (*12.28*)	0.3715*** (*12.38*)	0.3905*** (12.14)
t	0.0153* (*1.62*)	0.0239*** (3.90)		0.0083 (1.08)	0.0195* (2.13)	0.0172 (*1.99*)	0.0192** (*2.39*)	0.0194** (2.43)
$0.5(\ln K)^2$	0.0672* (*1.73*)		0.1364*** (3.97)	0.0915** (2.86)	0.0131 (0.3375)	0.0596 (*1.58*)	0.0582 (*1.52*)	0.0545* (1.42)
$0.5(\ln L)^2$	-0.0556 (*-1.36*)		-0.0957** (-2.44)	-0.0857* (-2.21)	0.0871** (2.31)	-0.0551 (*-1.36*)	-0.0519 (*-1.26*)	-0.0528* (-1.28)
$0.5(\ln M)^2$	0.1018*** (*7.66*)		0.0998*** (6.78)	0.1043*** (7.98)	0.0606*** (4.37)	0.1012*** (*7.62*)	0.1008*** (*7.70*)	0.1006*** (7.64)
$0.5(\ln E)^2$	0.2069*** (*7.95*)		0.1668*** (5.85)	0.1910*** (7.19)	0.2958*** (10.45)	0.2118*** (*8.41*)	0.2095*** (*7.94*)	0.2125*** (8.29)
$0.5t^2$	0.0009 (*1.36*)			0.0013** (2.41)	0.0006 (0.780)	0.0009 (*1.38*)	0.0008 (*1.30*)	0.0008 (1.34)
$(\ln K)(\ln L)$	-0.0418* (*-1.48*)		-0.0413 (-1.66)	-0.0143 (-0.537)	-0.8653*** (-4.37)	-0.0385 (*-1.39*)	-0.0373 (*-1.34*)	-0.0358 (-1.24)
$(\ln K)(\ln M)$	0.0395* (*2.09*)		0.0108 (0.629)	0.0051 (0.304)	0.0910*** (4.80)	0.0359 (*1.94*)	0.0370 (*1.95*)	0.0348* (1.84)
$(\ln L)(\ln M)$	0.0594*** (*3.26*)		0.0575*** (3.03)	0.0643*** (3.60)	0.0677*** (3.77)	0.0623*** (*3.45*)	0.0609*** (*3.34*)	0.0627*** (3.44)
$(\ln K)(\ln E)$	-0.0342 (*-1.33*)		-0.0598** (-2.51)	-0.0354 (-1.66)	0.0395* (1.46)	-0.0298 (*-1.19*)	-0.0292 (*-1.13*)	-0.0270 (-1.05)
$(\ln L)(\ln E)$	0.0337 (*1.09*)		0.0736 (2.39)	0.0368 (1.25)	-0.1137*** (-3.69)	0.0277 (*0.92*)	0.0259 (*0.859*)	0.0233 (0.795)
$(\ln M)(\ln E)$	-0.2288*** (*-19.88*)		-0.2029*** (-17.98)	-0.2141*** (-20.04)	-0.2328*** (-19.30)	-0.2293*** (*-19.99*)	-0.2280*** (*-20.06*)	-0.2286*** (-19.86)
$t(\ln K)$	0.0039 (*1.20*)				0.0090** (2.31)	0.0040 (*1.23*)	0.0039 (*1.20*)	0.0040** (2.42)
$t(\ln L)$	0.0065* (*2.29*)				0.0016 (0.5079)	0.0067* (*2.37*)	0.0070** (*2.49*)	0.0069** (2.47)
$t(\ln M)$	-0.0101*** (*-4.66*)				-0.0114*** (-4.58)	-0.0102*** (*-4.69*)	-0.0101*** (*-4.59*)	-0.0101*** (-4.62)
$t(\ln E)$	0.0018 (*0.63*)				0.0016 (0.4960)	0.0020 (*0.72*)	0.0015 (*0.546*)	0.0018*** (3.643)
s^2	0.1048** (*2.59*)	0.1515*** (7.21)	0.0674*** (6.36)	0.0971*** (3.58)	0.0584	0.1610*** (*4.57*)	0.1280** (*2.15*)	0.1740*** (5.48)
g	0.7041*** (*6.29*)	0.6621*** (21.50)	0.5283*** (9.85)	0.6729*** (7.54)	0.000	0.8060*** (*18.22*)	0.7569*** (*6.74*)	0.8203*** (23.88)
m	0.2359 (*0.235*)	0.6334*** (5.98)	0.3774*** (5.75)	0.3396 (2.57)		0.0000	0.1989 (*0.762*)	0.000
h	0.0084 (*0.845*)	0.0038 (0.388)	0.0384*** (9.17)	70.36 (0.729)		0.0056 (*0.627*)	0.0000	0.000
Log-likelihood	181.14	-62.96	151.49	167.88	11.51	180.80	180.78	180.62

Notes: (1) The dependent variable for frontier estimation is $\ln y_{it}$ and total number of observations is 887

(2) The values in parentheses below the coefficients show the t-statistics.

(3) *, **, ***, show the 10 per cent, 5 per cent and 1 per cent level of significance respectively.

Table 5: TESTS OF HYPOTHESIS FOR PARAMETERS OF THE DISTRIBUTION OF THE TECHNICAL INEFFICIENCY EFFECTS (Uit) AND APPROPRIATENESS OF THE FUNCTIONAL FORM

Models	Null Hypothesis	Test stat (l)	$c^2_{0.010}$	$c^2_{0.050}$	Decision
Model 1.1	H_0: all b s = 0	488.2	30.5779	24.9958	Reject H_0
Model 1.2	$H_0\ a_t = b_{tt} = b_{tL} = b_{tK} = b_{tM} = b_{tE} = 0$	59.30	16.8119	12.5916	Reject H_0
Model 1.3	H_0: $b_{tk} = b_{tl} = b_{tm} = b_{te} = 0$	26.52	13.2767	9.4877	Reject H_0
Model 1.4	H_0: $g = m = h = 0$	339.26	10.50	7.04	Reject H_0
Model 1.5	H_0: $m = 0$	0.68	6.6349	3.8414	Accept H_0
Model 1.6	H_0: $h = 0$	0.72	6.6349	3.8414	Accept H_0
Model 1.7	H_0: $m = h = 0$	1.02	5.99	9.21	Accept H_0

***** The critical value for this test involving g = 0 is obtained from Table 1 of Kodde and Palm (1986,p. 1246)

Technical efficiency of the cement companies

The estimated average technical efficiency of the cement companies is as high as 0.75 which implies that the companies are operating at 75% of their potential output determined by the frontier technology. But statistical test suggests that technical efficiency of the cement companies is time invariant in nature, i.e. overtime changes in technical efficiency are not statistically significant in spite of a moderate level of technical progress taking place in the industry. So it can be inferred from this result that each year or within a couple of years the innovating firms keep on shifting for better technologies; however, for various reasons, such as incomplete knowledge of the best practice and other organizational factors, they are unable to follow the best practice techniques of the chosen technology. As a result, the firms fail to obtain 100% technical efficiency and the level of efficiency seems to be more or less at the same percentage level over the year. On the other hand, non-innovator firms, due to technology spill over, are also moving towards the best practice frontier i.e they are catching up with the frontier and thereby maintaining the same distance from the frontier set by the best practice techniques. The possible reasons for which none of the cement companies is able to follow the best practice techniques and thereby attaining 100 % efficiency, are as follows. Due to inadequate number of domestic machinery suppliers, most of the machineries and equipments used in the Indian cement industry are borrowed from abroad. There are certain factors which lead to poor absorption and adaptation capabilities of the borrowed technology. *Firstly*, poor infrastructure of the receiving companies; *Secondly,* very limited R&D activities of the recipient companies; *thirdly*, inadequate technology support services of the Indian companies and *lastly*, absence of any long term training programme for the local personnel[4] Since technical efficiency has not improved over the year, it has not contributed to TFP growth.

Technical Progress, Scale Components and Total Factor Productivity growth

Table 6 presents the averages of the rates of technical progress (TP), the scale components (SC) and the total factor productivity (TFP) growth of the cement companies for the selected time period. The average rate of TP is estimated at 2.59 per cent which increased continuously in the total sample during the sampling period. The rate of technical progress starts at a comparatively low level of 1.59 per cent, increasing to 3.35 per cent during 2004-07. The new industrial policy and the process of economic reforms in the Indian economy, initiated in 1985, and complete decontrol of the cement industry after 1989, can be cited as the most probable reason for this very impressive technological progress.

Scale components, which measure the effects of input changes on output growth, are zero if RTS is constant, or are greater (less) than zero if RTS is increasing or decreasing, assuming positive input growth (Kim et,al.2001). It can be seen from the following table that SC shows an increasing trend except for the period 1998-00 and 2000-02. Average scale components are 3.27 per cent for the whole industry. So there is an opportunity for most of the companies to grow large enough to exploit scale economies that exist in the industry. Due to the presence of scale economies, Indian cement industry has witnessed a lot of mergers and acquisitions (M&As) in the last couple of years. Some examples of consolidations witnessed during the recent past include: Gujrat Ambuja taking stake of 14% of ACC; Gujrat Ambuja taking over DLF cements and Modi Cement; India Cement taking over Raasi cement and Sri Visnu Cement; Grasim's acquisition of cement business of L&T; ACC taking over IDCOL; Grasim taking over Sri Digvijay Cements and so on. Multinational companies have also initiated acquisition process in the Indian cement market.

Table6: Annual average of Technical progress (TP), scale components (SC) and total factor productivity Growth (TFPG) of Indian cement companies (in percentage)

Year	TP (%)	SC (%)	TFPG (%)
1989-90	1.59	-0.03	1.56
1990-92	1.87	2.27	4.14
1992-94	2.03	4.75	6.78
1994-96	2.19	5.50	7.69
1996-98	2.39	7.20	9.59
1998-00	2.79	1.47	4.26
2000-02	2.95	-1.21	1.74
2002-04	3.11	1.73	4.84
2004-07	3.35	4.46	7.81
1990-07	2.47	2.90	5.37

Source: Author's calculations

As we have already mentioned that technical efficiency of the cement companies is time invariant in nature, i.e. changes in technical efficiency during the study period is not statistically significant. In the absence of technical efficiency change, TFP growth of the cement companies is calculated as the sum of technical progress (TP), as measured by a shift in the production frontier and changes in scale components. In the Indian cement industry, TFP growth is dictated by SC for most of the years except 1998-00 and 2000-02. It is clear from Table 6 that TFP has grown at an annual rate of 5.37 per cent and also it shows an increasing trend except for the periods 1998-00 and 2000-02. The reason for the slow down of TFP growth between 1998-00 and 2000-02 may be due to the East Asian Crisis (1998-00). Results show that annual growth in TFP in the Indian cement industry during the study period accounts for only 5.37% implying that 94.63% of the output growth has been achieved through input growth.

Conclusions

This paper estimates Total Factor Productivity (TFP) growth in Indian cement industry during the period 1989-90 to 2006-07 using company level data and applying Stochastic Frontier Approach. Most of the earlier studies relating to productivity growth in Indian manufacturing, measured TFP growth as a residual of the "Solow" growth accounting or used index number approach to measure TFP growth. Compared to earlier studies related to Indian cement industry, this paper has two major improvements. *Firstly,* estimating TFP growth with frontier approach which helps examine the role of technical progress as well as technical efficiency change and scale component in TFP growth. *Secondly,* including energy as a separate factor of production in the production function and demonstrating the direction of technical change towards each input. Empirical results of this study show that productivity growth of Indian cement companies is driven significantly by scale effects, which implies that there is a scope for the cement companies to grow optimally for exploiting the potential economies of scale. Technical progress also has a positive and significant impact on productivity growth. Though the average level of technical efficiency of the cement companies is as high as 75%, yet the result suggests that technical efficiency does not play any significant role on productivity growth because technical efficiency is not found improving overtime. Though estimated TFP growth in this study is found higher than that of earlier studies, TFP growth can explain on 5.37% of the output growth in Indian cement industry. So 94.63% of output growth has been achieved through input growth. The measures of TFP growth components not only provide more insights and better understanding of the dynamic nature of the production process, but also have important policy implications. For example, policy action intended to improve TFP growth rate might be misdirected if they focus on accelerating the rate of innovation in circumstances where the low rate of TFP growth is brought about by suboptimal size of the firms and low rate of technology diffusion (technical inefficiency), which really happened in the case of Indian manufacturing sector in general. A thorough examination of industrial policy resolutions and five- year plans reveals that the importance and contribution of efficiency in industrial growth has been neglected or given less priority in the framework of industrial strategy (Madheswaran, et al., 2007). In this context, the governments should take some action to improve productive efficiency of the cement companies. Once efficiency increases, it enhances competitiveness by realizing the potential output.

If non-improvement of technical efficiency over the years is one area of concern the government should look into, direction of technical change is another area firms should concentrate on. Empirical results of the study suggest that technical change in the Indian cement companies involves an energy using bias. Now, energy using technical change in an energy intensive industry like cement is not only undesirable but also unsustainable at the same time. Energy using technological change may have some dampening effect on energy productivity and thereby on the competitiveness of the industry. To improve energy efficiency and energy productivity to a greater extent, firms should adopt such technologies which may save energy or which don't have an energy using bias in-build into them.

Appendices

1. Estimation of capital stock

In many of our empirical analyses, mostly in productivity related studies, we use capital as a variable. But it is a daunting task for the researchers to estimate capital stock accurately. Generally, capital stock is valued at historic cost which is called book value of capital, but what we need is the present value of capital stock at constant prices. One of the methods to obtain the present value of capital stock at constant prices relates to Perpetual Inventory Method (PIM). There are several variations of this method. We have adopted the approach originally set out by Balakrishnan et al. (2000). The methodology involves the following steps based on certain assumptions:

(i) We choose 1995 as the benchmark year due to availability of largest number of observations in that particular year and assume that the earliest vintage of capital dates from 1975 or from the year of incorporation of the company, if it is after 1975. The year 1975 itself was chosen because the life of machinery is assumed to be 20 years as noted in Report of the Census Machine Tools 1986' of the Census Machine Tools Institute, Bangalore ('National Accounts Statistics: Sources and Methods', Central Statistical Organization, New Delhi, 1989).

(ii) Price of capital changes at constant rate $\Pi = \frac{P_t - P_{t-1}}{P_{t-1}}$ from 1975 or from the year of incorporation upto 1995. The values of Π were calculated from a series of price deflators based on CSO's data on gross fixed capital formation for various years published in various issues of the *National Accounts Statistics* (NAS).

(iii) Similar to price of capital, we assume that investment also changes at a constant rate $g = \frac{I_t - I_{t-1}}{I_{t-1}}$ from 1975 or from the year of incorporation upto 1995. The growth of fixed capital formation at 1980-81 prices, taken from various issues of NAS, is applied to all firms.

(iv) Based on the value of Π and g, we have calculated the 'r-evaluation factor', R^G, defined by Balakrishnan et al. (2000) as,

$$R^G = \left[(1+g)^{t+1} - 1\right]\left[(1+\Pi)^t \left\{(1+g)(1+\Pi) - 1\right\}\right] / g\left\{(1+g)(1+\Pi)^{t+1} - 1\right\}$$

Where t being the length of life of capital goods; we have used a maximum of 20 years as the length of the life of the capital stock. We have taken the value of t =20 for the firms whose incorporation year is 1975 or before; for all other firms, t is calculated as the difference between the benchmark year (1995) and the year of incorporation.

(v) Once the 're-valuation factor' is calculated, we have multiplied the capital stock in the base year (1995) by this factor for converting the base year capital into capital stock at replacement cost at current prices.

(vi) The value of capital stock in the base year is then converted into constant prices using the WPI for machinery with the year 1993-94 as base.

(vii) Capital stock in the subsequent years is then estimated by adding subsequent years' investment, $GFA_t - GFA_{t-1}$, (at constant prices) to the existing capital stock at each point of time using perpetual inventory method.

2. Testing monotonicity and quasi-concavity of the estimated function

Since we fit a translog function, we must check whether the fitted function is well behaved, i.e. consistent with the production theory. This is usually done by checking two things: A. monotonicity and B. quasi-concavity

Monotonicity

As is well known with respect to a (single output) production function, monotonicity requires positive marginal products with respect to all inputs: $\frac{\partial y}{\partial x_i} \succ 0$ (1)

and thus non-negative input elasticities. In case of the translog production function the marginal product of input i is obtained by multiplying the logarithmic marginal product with the average product of input i. The monotonicity condition given in (1) holds for the translog specification if the following equation is positive:

$$\frac{\partial y}{\partial x_i} = \frac{y}{x_i} * \frac{\partial \ln y}{\partial \ln x_i} = \frac{y}{x_i} * \left(a_i + \sum_{j=1}^{n} a_{ij} \ln x_j \right) \succ 0 \qquad (2)$$

Since both y and x_i are positive numbers, monotonicity depends on the sign of the term in the parenthesis, i.e., non-negative elasticity of y with respect to x_i. The condition of non-negative input elasticity should hold good at least at the point of approximation which is sample mean here. Since we already mean-corrected the data prior to the estimation, the estimated first-order parameters in the translog function can be directly interpreted as estimates of the production elasticities, evaluated at the sample means. The following table presents the value of each of the input elasticities and returns to scale (RTS) measured by sum of the elasticities.

Appendix Table 1: Elasticities and RTS at sample means

Labor	Capital	Material	Energy	RTS
0.1330	0.2323	0.3552	0.3764	1.0969

We have computed each of the input elasticities for each firm and for each year and found that in each year more than 90% of the firms show positive input elasticity in each year.

Quasi-concavity

This condition is related to the curvature of the production function. It implies a convex input requirement set (see in detail, e.g., Chambers 1988).The necessary and sufficient condition for a specific curvature consists in the semi-definiteness of its bordered Hessian matrix as the Jacobian of the derivatives $\frac{\partial y}{\partial x_i}$ with respect to x_i : if $\nabla^2 Y(x)$ is negatively semi-definite, Y is quasi-concave, where ∇^2 denotes the matrix of second order partial derivatives with respect to $f(\cdot)$. With respect to the translog production function curvature depends on the input bundle, as the corresponding bordered Hessian **BH** for 2 input case shows:

$$\begin{pmatrix} 0 & f_1 & f_2 \\ f_1 & f_{11} & f_{12} \\ f_2 & f_{21} & f_{22} \end{pmatrix}$$, the **BH**

Where elements inside the matrix are first partial, second partial and cross partial derivatives of the production function. The quasi concavity condition will be satisfied if the major principal minors of the Hessian Matrix are alternating in sign starting from negative. In our analysis more than 90% of the firms satisfy both monotonicity and quasi-concavity condition in each year.

End Notes

[1] For details of the energy efficiency policies initiated by the Indian Government, see Yang, 2006.

[2] This section is based on ICRA Sector Analysis (2006).

[3] For a detailed account of the literature related to productivity growth of Indian cement industry during the period 1945 to 1985, see Mongia et al. (1998).

[4] These factors have been identified in a report prepared by National Council for Cement and Building materials (NCB), 2006.

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