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India's Cement Industry: Productivity, Energy Efficiency and Carbon Emissions

Katja Schumacher and Jayant Sathaye

Environmental Energy Technologies Division

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Katja Schumacher[*] and Jayant Sathaye

Energy Analysis Program
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory
Berkeley, CA 94720

[*]Fax: (510) 486-6996, Email: KBSchumacher@lbl.gov

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Abstract

Historical estimates of productivity growth in India's cement sector vary from indicating an improvement to a decline in the sector's productivity. The variance may be traced to the time period of study, source of data for analysis, and type of indices and econometric specifications used for reporting productivity growth. We derive both growth accounting and econometric estimates of productivity growth for this sector. Our results show that over the observed period from 1973-74 to 1993-94 productivity increased by 0.8% as indicated by the Translog index. Calculations of the Kendrick and Solow index support this finding. The increase was mainly driven by a period of progress between 1983 and 1991 following partial decontrol of the cement sector in 1982. Before 1983, productivity declined probably due to government protection regarding prices and distribution, inefficiencies in plant operation and constraints in essential input factors. Between 1991 and 1993, the sector suffered a downfall in accordance with overall economic recession. Using a translog specification the econometric analysis reveals that technical progress in India's cement sector has been biased towards the use of energy and capital, while it has been material and labor saving. We examine the current changes in structure and energy efficiency undergoing in the sector. Our analysis shows that the Indian cement sector is moving towards world-best technology, which will result in fewer carbon emissions and more efficient energy use. However, substantial further energy savings and carbon reduction potentials still exist.

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1. Introduction

The cement industry presents one of the most energy-intensive sectors within the Indian economy and is therefore of particular interest in the context of both local and global environmental discussions. Increases in productivity through the adoption of more efficient and cleaner technologies in the manufacturing sector will be effective in merging economic, environmental, and social development objectives. A historical examination of productivity growth in India's industries embedded into a broader analysis of structural composition and policy changes will help identify potential future development strategies that lead towards a more sustainable development path.

Issues of productivity growth and patterns of substitution in the cement sector as well as in other energy-intensive industries in India have been discussed from various perspectives. Historical estimates vary from indicating an improvement to a decline in the sector's productivity. The variation depends mainly on the time period considered, the source of data, the type of indices and econometric specifications used for reporting productivity growth. Regarding patterns of substitution most analyses focus on interfuel substitution possibilities in the context of rising energy demand. Not much research has been conducted on patterns of substitution among the primary and secondary input factors: Capital, labor, energy and materials. However, analyzing the use and substitution possibilities of these factors as well as identifying the main drivers of productivity growth among these and other factors is of special importance for understanding technological and overall development of an industry.

In this paper, we contribute to the discussion on productivity growth and the role of technological change within the context of global environmental change. We introduce the cement industry in more detail taking into account industry specific aspects such as structural composition, production, technologies, energy consumption within processes, environmental impacts, sector specific policies etc. Subsequently, we derive both statistical and econometric estimates of productivity growth for the cement sector over time. For the statistical analysis we calculated partial and total productivity in a growth accounting framework while for the econometric analysis a translog cost function approach is employed to estimate productivity growth, technical change biases and substitution elasticities. The results are then interpreted within a broader context of structural and policy changes in the sector as well as other sector specific aspects.

Future energy use and carbon emissions depend mainly on the level of production and the technologies employed. Furthermore, different economic and policy settings affect structures and efficiencies within the sector. The final section therefore examines the ongoing changes in the cement industry structure. It compares world best technologies to Indian technologies and identify potentials and barriers to the achievement of efficiency improvements. A scenario analysis concludes the report in highlighting the energy efficiency and productivity improvements that could be achieved by employing more efficient technologies.

2. Cement Industry

2.1 The Cement Industry in Context

In the course of this study, six industries in India have been identified as energy-intensive industries: Aluminum, cement, fertilizer, iron and steel, glass, and paper. Together they account for 16.8% of manufacturing value of output (VO) and for 38.8% of all fuels consumed in the manufacturing sector (Table 2.1). The cement sector holds a considerable share within these energy-intensive industries. In 1993, it accounted for 11.7% of the value of output within the six industries and for 2.0% of that in the manufacturing sector.

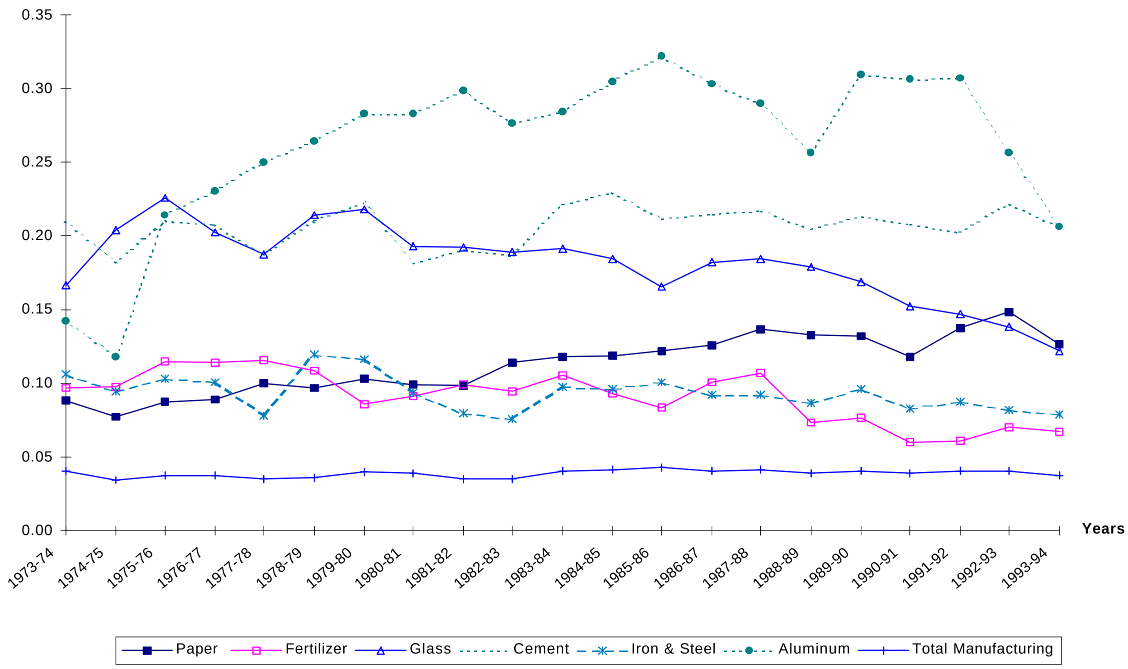
Table 2.1: Economic Indicators for the Cement Industry

	Unit	Cement	Aggregate of Six Energy-intensive Industries	Aggregate Manufacturing
Growth in Value of Output[1]				
Nominal				
1973-1993	% p.a.	16.7	16.4	15.1
1973-1983	% p.a.	18.8	18.1	15.3
1983-1991	% p.a.	17.5	15.4	14.6
1991-1993	% p.a.	3.2	12.2	16.2
Real				
1973-1993	% p.a.	8.7	7.9	7.4
1973-1983	% p.a.	6.3	8.6	7.7
1983-1991	% p.a.	13.7	8.9	6.9
1991-1993	% p.a.	0.4	0.4	7.3
In 1993-94:				
VO Share in Aggr. Manufacturing (nominal)	Sector VO/ Manuf. VO	2.0%	16.8%	100%
Nom. Sector Fuel Share in Aggr. Manuf. (nominal)	Sector Fuel/ Manuf. Fuel	10.3%	38.8%	100%
Fuel Cost Share in Value of Output (nominal)	Sector Fuel/ Sector VO	35.5%	15.8%	6.8%
Source: Government of India, ASI: Summary Results for the Factory Sector (various years).				

[1] calculated as exponential annual growth.

Production in the cement sector has been increasing over the last 20 years. Over the study period 1973-1993, real VO increased by an average of 8.7% p.a. Following the fertilizer industry the cement sector shows second highest growth in the group of energy-intensive industries. Major cement-specific policy changes took place in 1982 and 1989. As seen in Table 2.1 growth of real value of output was around 6.3% during the period of total control (1973-1983). It increased significantly to 13.7% in the following period of partial and eventually total decontrol (1983-91), accounting for higher than average growth in both the group of six energy-intensive industries and total manufacturing. After 1991, the real value of output growth was substantially lower at 0.4% until 1993.

Figure 2.1: Changes in Physical Energy Intensity of Various Industries
(Real Fuel Cost/Real Value of Output - 1973-74 values)



The cement sector accounts for 10.3% of total fuel costs in the manufacturing sector. The fuel cost share, fuel costs per unit of output (VO), in the cement sector is more than two times higher than the average fuel cost share of the six energy-intensive industries and amounts to more than five times the average of total manufacturing. Within the group of energy-intensive industries the sector, therefore, holds the lead in energy intensity measured as the nominal value of fuels consumed compared to the nominal value of output. Figure 2.1 displays the energy intensity of the cement sector in real values. The 'real-value' indicator reflects the changes in physical energy intensity over time and gives a comparison to other sectors. Except for aluminum, cement production has been most energy intensive not only in 1993 but almost over the whole time period. Despite its fluctuating pattern it shows a relatively stable trend over time.

2.2. Cement Process

Cement acts as a bonding agent, holding particles of aggregate together to form concrete. Cement production is highly energy intensive and involves the chemical combination of calcium carbonate (limestone), silica, alumina, iron ore, and small amounts of other materials. Cement is produced by burning limestone to make clinker, and the clinker is blended with additives and then finely ground to produce different cement types. Desired physical and chemical properties of cement can be obtained by changing the percentages of the basic chemical components (CaO, Al_2O_3, Fe_2O_3, MgO, SO_3, etc.).

Most cement produced is portland cement: other cement types include white, masonry, slag, aluminous, and regulated-set cement. Cement production involves quarrying and preparing the raw materials, producing clinker through pyroprocessing the materials in huge rotary kilns at high temperatures, and grinding the resulting product into fine powder. The following detailed description is borrowed from the World Energy Council (1995).

2.2.1 Raw Materials Preparation

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 processes, and blending the materials. The energy consumption in raw materials preparation accounts for a small fraction of overall primary energy consumption (less than 5%) although it represents a large part of the electricity consumption.

2.2.2. Clinker Production

Clinker production is the most energy-intensive step, accounting for about 80% of the energy used in cement production in the United States. Produced by burning a mixture of materials, mainly limestone ($CaCO_3$), silicon oxides (SiO_2), aluminum, and iron oxides, clinker is made by one of 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.

In the wet process, the crushed and proportioned materials are ground with water, mixed, and fed into the kiln in the form of a slurry. In the dry process, the raw materials are ground, mixed, and fed into the kiln in their dry state. The choice among different processes is dictated by the characteristics and availability of raw materials. For example, a wet process may be necessary for raw materials with high moisture content (greater than 15%) or for certain chalks and alloys that can best be processed as a slurry. However, the dry process is the more modern and energy-efficient configuration.

Once the materials are ground, they are fed into a kiln for burning. In modern kilns, the raw material is preheated (in four to five stages) using the waste heat of the kiln, or it is pre-calcined. During the burning or pyroprocessing, the water is first evaporated after which the chemical composition is changed, and a partial melt is produced. The solid material and the partial melt combine into small marble-sized pellets called clinker.

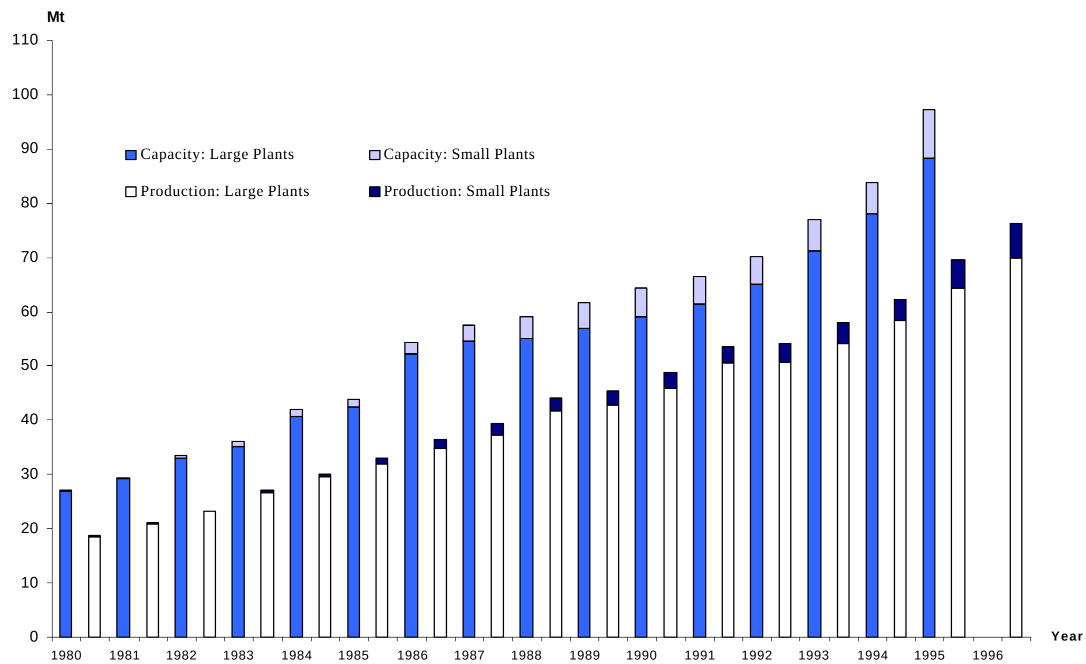
2.2.3 Finish Grinding

Cooled clinker is ground in tube or roller mills and blended by simultaneous grinding and mixing with additives (e.g., gypsum, anhydrite, pozzolana, fly-ash or blast furnace slags) to produce the cement. Drying of the additives may be needed at this stage.

2.3 Cement Production in India

Following China, Japan and the US, India is the fourth largest cement-producing country in the world. In 1996, around 115 large cement plants within 57 cement companies and about 300 small plants produced 76.2 million tonnes[1] (Mt) cement per year. Ownership is mostly private (85% of installed capacity) and centralized for the large plants with four production houses controlling most units. This has led to financial and administrative integration of different factories. (Datt and Sundharam, 1998) Installed capacity increased considerably between 1970 and 1996, particularly in the last few years following complete deregulation of the cement sector. While in the two decade period from 1970 to 1990 total installed capacity rose by around 47 million tonnes from 17 million tonnes to 64 million tonnes, within only 6 years between 1990 and 1996 it increased by another 41 million tonnes to 105 million tonnes of installed capacity.

Figure 2.2: Production and Installed Capacity - Small and Large Cement Plants



Source: Karwa (1998).

Production, however, did not increase accordingly. Due to a high frequency of power failures, shortage of coal, inadequate availability of wagons for rail transportation, limited availability of furnace oil etc. capacity utilization decreased steadily from as high as 90% in 1978 to a low point of 67% in 1980-81. Following policy changes towards deregulation in the early and late 1980s capacity utilization reimproved to 82% in 1991-92. Yet, since then it has again shown a decreasing trend to 72% in 1996-97. (Datt and Sundharam, 1998; Karwa, 1998) Figure 2.2 shows installed capacity and production for large as well

[1] metric tonnes, sometimes abbreviated as t, or million tonnes as Mt in the following.

as small plants. Appendix A gives production, capacity and capacity utilization from 1970-96 for India as a whole and Table 2.2 by region for 1995-96.

Table 2.2 shows that, in 1995-96, cement production in India is regionally quite dispersed with major clusters in the west and the south. Installed capacity as well as production is highest in the west. However, as capacity utilization at 90.9% is substantially better in the south, cement output in the south is only slightly lower than in the west. This pattern - high levels of installed capacity at relatively low utilization level in the west resulting in roughly the same output as in the south where capacity utilization is higher at lower levels of installed capacity - can be observed for previous years 1991-1995 as well. It is noteworthy that, in contrast to the national development, capacity utilization in the south improved continuously between 1991 and 1995.

Table 2.2: Regionwise Cement Production, Capacity, and Capacity Utilization (million tonnes) **Year: 1995-96**

Region	Capacity	Production	Capacity Utilization (%)
North	18.3	12.1	66
East	7.3	4.6	63
West	38.6	25.9	67
South	23.9	21.7	91
All India	88.2	64.4	73

Source: Karwa (1998).

The viability of the location plays a major role in the economics of cement manufacturing. It is determined by factors such as proximity to raw materials (limestone, coal), distance to market areas as well as availability of continuous power supply. Proximity to limestone deposits contributes considerably to pushing down costs in transportation of heavy limestone. If units are located close enough to limestone resources, trucks can be used to move limestone over the short distance instead of relying on scarce railway capacity.

The proximity of coal deposits constitutes another important factor in cement manufacturing. Generally, coal is transported by railway throughout the country. Coal distribution and coal prices are strictly controlled by the government. Although coal deposits are located all over the country constraints in availability of wagons for railway transportation have led to major shortfalls in the amount of coal received against the quota assigned to the cement industry. For the year 1973, Chakravarty (1989) computed losses in cement production due to coal shortages of up to 37%. However, they were considerably lower at 10% in 1981 and have since steadily decreased. In 1987, coal shortage accounted for only 0.4% of production losses.

In order to reduce transportation as well as capital costs, to increase regional development and to make use of smaller limestone deposits many small and mini cement plants with a capacity of up to 650 tonnes per day were set up in dispersed locations in India. As seen in Figure 2.2, construction of such plants began in the early 1980s and amounted to 180 mini cement plants in 1992 together producing 3 Mt (about 6% of total cement production) and 311 plants producing 5 Mt (7.3% of total cement) in 1996. (World Energy Council, 1995; International Cement Review, 1998).

Despite the advantages, there were several drawbacks associated with the setting up of units in dispersed areas, mainly due to increased distances to market areas other than the local markets. Limits in transportation capacity, particular in rail transport, constrained the delivery of cement from the production site to the consumer. Consequently, due to lack of storage capacity (silos) at the production site producers were often forced to cut back cement production. Only in recent years the government finally allowed the cement industry to purchase and own rail wagons to overcome these problems.

Demand for cement has been growing at rates of up to 10% p.a. in the past. While in 1987 demand was about 37 million tonnes (Mt), it reached 53 Mt in 1993 and further increased to more than 65 Mt in 1995 (CMA, 1994 and Karwa, 1998). Providing a main input for construction, cement consumption is highly dependent on activities in the construction sector which are in turn dependent on governmental and private investment in infrastructure and buildings. Appendix B provides gross value added in the construction sector from 1977-95. During most of the past, demand could not be met by national production. Therefore, imports had to fill the balance. Since 1987, however, cement production has increased and India reached self-sufficiency. And, more recently exports, particularly to neighboring countries, have been increasing. (Mittal, 1994)

At present the Indian cement industry produces 13 different varieties of cement employing three different process types. Amongst the varieties, Ordinary Portland Cement (OPC), Portland Pozzolana Cement (PPC) and Portland Slag Cement (PSC) constitute the major shares accounting for almost 99% in total production. Ordinary Portland Cement is most commonly used in India. It holds a share of about 70% in total production. PPC production accounts for about 18% of total cement production while PSC assumes a share of only 11%. (Karwa, 1998) Generally, the two varieties, PSC and OPC, can be used for same purposes, while PPC cannot be used for prestressed and high strength concrete, as used in bridges and airports (Das and Kandpal, 1997)

Cement is produced using the wet, the semi-dry, and the dry processes. The shareo f the wet process in total installed capacity has declined from over 90% in 1960 to only 12% today (Table 2.3). The wet process has been substituted by the significantly less energy-using dry process over time. Following the two oil price shocks the shift in technology mix has become substantial. The dry process nowadays accounts for the majority (86%) of India’s cement production. Due to new, even more efficient technologies, the wet process is expected to be completely pushed out in the near future.

The semi-dry process never played an important role in Indian cement production. Its share in total installed cement capacity has been small over time. It currently accounts for 2% of total production. Mini cement plants usually use vertical shaft kilns for cement production.

Table 2.3 Technology Mix (%) for Cement Production in India

Technology	1960	1970	1980	1993	1997
Dry process	1.1	21.5	32.7	82.0	86.0
Semi-dry process	4.5	9.0	5.7	2.0	2.0
Wet process	94.4	69.5	61.6	16.0	12.0
Source: TERI, 1994; Karwa (1998).					

2.3.1 Raw Materials

Limestone presents the major raw material input to cement production. High quality limestone is accessible almost all over the country. For the production of OPC, clay and gypsum serve as additives while the production of PPC and PSC requires additives that can be taken from industrial wastes such as fly ash and blast furnace slag respectively. Neither of these inputs currently places any constraint in terms of availability or quality on the production of cement. Fly ash can be recovered as a waste product from electricity generation while slag residues from blast furnace of steel plants.

2.3.2 Energy Use

Energy consumption per tonne of cement varies from technology to technology. The dry process uses more electrical but much less thermal energy than the wet process. Overall, it requires substantially less total energy. Additionally, as shown in Table 2.4 energy consumption per tonne of clinker (cement respectively) in the dry process has been declining over the past. The increase in final energy consumption in 1993 is solely due to an increase in the clinker/cement ratio for that year.

Table 2.4 Energy Consumption in Indian Cement Industry (1991-1993)

Process	Thermal Energy GJ/t clinker			Electricity GJ/t cement			Final Energy GJ/t cement*		
	1991	1992	1993	1991	1992	1993	1991	1992	1993
Dry Process Plants	3.58	3.47	3.41	0.43	0.41	0.40	3.45	3.30	3.40
Semi Dry Process Plants	4.02	3.95	3.95	0.44	0.42	0.41	3.82	3.71	3.88
Wet Process Plants	5.53	5.69	5.61	0.39	0.39	0.36	5.05	5.13	5.29
Source: Karwa (1998).									

*calculated for a clinker-cement ratio of 0.842 (1991), 0.833 (1992), 0.878 (1993).

Primary energy consumption in a typical dry process Portland Cement Plant as found in industrialized countries consists of up to 75% of fossil fuel consumption and up to 25% of electricity consumption. Within the fuel category pyroprocessing requires the most energy, consuming 99% of the fuel energy while electricity is mainly used to operate both raw material (33%) and clinker (38%) crushing and grinding equipment. In addition, electricity is needed for pyroprocessing (22%) making it by far the most energy intensive step of the production process. India’s cement units are generally less energy efficient using both more thermal and electrical energy. However, the shares of energy used within the different sections of production are about the same. (Karwa, 1998)

Table 2.5: Fuel Consumption in the Indian Cement Industry 1991-1993

Fuel	Units	1991-92	1992-93	1993-94
Electricity*	GWh	4800.52	6420.97	6754.60
Coal	Mt	10.8	11.7	11.1
Petroleum Products	Mt	0.293	0.296	0.291
Total Cement Production	Mt	53.6	54.1	58.0
Source: TERI (1996, 1997); Government of India, ASI (1991-1993).				

*Electricity consumption includes purchased and captive power (excluding sales).

About 94% of the thermal energy requirement in the Indian cement manufacturing is met by coal. The remaining part is met by fuel oil and high speed diesel oil (see Table 2.5). So far, no real substitute for coal exists. Increasing the oil share would imply significant outflows of foreign exchange and impose a burden on the economy. Natural gas is mainly used as feedstock in newly-built large fertilizer plants and is thus not sufficiently available for the cement industry.

Actual coal consumption varies with qualitative factors. Over the years there has been a steady decline in the quality of coal. In particular, the ash content of coal has increased implying lower calorific values of coal, and improper and inefficient burning, ash ring formation in the kiln etc. Coal consumption thus had to be increased to provide the energy needed for clinker production resulting in additional costs for transportation, handling, grinding and burning of coal. In order to reduce these problems the cement industry started implementing coal washeries which reduce the ash content of coal at the mine itself.

Generally, power is provided by the State Electricity Boards. Yet, problems in power supply, such as frequent power cuts, power failures and low voltage, impose immense problems on the cement industry. Interruption of power affects the industry negatively by causing production losses and low capacity utilization, idle running of equipment during stop and restart of the plant, thermal losses during reheating, damages to refractory etc. Cement companies have therefore started installing captive power to ensure continuos running of process plants and emergency equipment. In 1993, 974 GWh of electricity was produced onsite (Government of India, Annual Survey of Industry, 1993).

2.4 Policy

The Indian cement sector has been under strict government control for almost the whole period since independence in 1947. Government intervention took place both directly and indirectly. Direct intervention happened in the form of government control over production capacity and distribution of cement, while indirect intervention took the form of price control.

Table 2.6 provides a summary overview of major policy changes between 1951 and today. Three significant periods can be distinguished: First, the period of total control where both prices and distribution of output were strictly regulated by the government. Second, the period of partial decontrol starting in Feb. 1982 and finally the period since 1989 when all price and distribution controls were withdrawn.

The price and distribution control system on cement, implemented after liberalization in 1956, aimed at ensuring fair prices to producers and consumers all over the country, thus reducing regional imbalances, and at reaching self-sufficiency within a short time horizon. Because of slow growth in capacity expansion and continued cost increases, the government had to increase the fixed price several times. However, these price increases as well as financial incentives (tax returns on capital) to enhance investment showed little to no effect on the industry. In 1977, higher prices were allowed for cement produced by new plants or major expansions of existing plants. Due to sustained slow development the uniform price imposed by the government was substituted by a three tier price system in 1979. Different prices were assigned to cement produced in low, medium and high cost plants.

However, further increases of input costs (including those that were likewise regulated by the government such as fuel and power costs as well as wages) could not be neutralized adequately and in time. Thus, the controlled price did not reflect the true economic cost and profit margins dwindled increasingly deterring essential investments in capacity and production expansion. A permit system introduced by 14 states and unified territories in the 1970s comprised direct control over public distribution of cement to ensure fair supplies to priority sectors, discourage consumption of cement for non-priority and essential purposes. Furthermore, it was thought to facilitate cement availability to small users and to eliminate black marketing. However, the system resulted in artificial shortages, extensive black marketing and corruption in the civil supply departments of the government (Datt and Sundharam, 1998).

The system of price control was accompanied by a policy of freight pooling. The price control fixed a uniform price according to estimated production costs at which cement was required to be sold all over the country. This price contained a freight component that was averaged over the country as a whole. If the actual freight component experienced by a particular firm was lower than the element included in the uniform price, producers had to pass on to the pool a sum representing the difference between the uniform price freight component and the freight costs incurred by them. On the other hand, if the actual freight incidence was higher than the freight element accounted for in the uniform price, producers were reimbursed the difference.

The freight pooling system promoted equal industrial development all over the country. It supported regional dissemination and ensured that cement was available at equal prices in any part of the country. Yet, it also implied that producers had no incentive in locating production such that transportation costs of cement would be minimized. Market distance became a less important issue. As a result of non optimal location of industries, average costs of production as well as demand for scarce railway capacity increased. (Ahluwalia, 1985 and Chakravarty, 1989)

Table 2.6: Overview of Policies Regarding the Cement Industry (1973 - 1993)

Period	Policy	Specifics	Notes
1951 – 1982	Price and Distribution Control		
April 1975		14% tax return on capital employed	Did not show any noticeable impact on industry
1977		12% post tax return on net worth	Showed effect on output
Until 1978		Uniform retention price	
May 1979		Three tier price system (different retention prices for low, medium and high cost plants)	
Feb. 1982	Partial Decontrol	Levy Obligation, Uniform Retention Price	Retention price slightly lower for PPC than OPC, specific mini units exempted from price and distribution control
1982-1988		Progressive decrease in levy and increase in retention price	See table below
Since 1986		Rebate in excise duty for new plants	
March 1989	Withdrawal of all price and distribution controls		
Until 1989	Freight Pooling		No freight pooling for non levy cement since 1982
Until 1991	Industrial licensing		
Source: Indian Economy (1998), Ahluwalia (1985, 1991), and Chakravarty (1989).			

On account of these difficulties in the cement industry the government of India introduced a system of partial decontrol in 1982. A levy quota of 66.6% for sales to government and small house builders was imposed on existing units while for new and sick units a lower quota at 50% was established. Levy cement was fixed uniformly for OPC and slightly lower for PPC. The balance of 33.4% could be sold in the free open market to general consumers. A ceiling price was set for sales in the open market in order to protect consumers from unreasonable high pricing. Under the system of partial decontrol non levy cement was no longer covered by freight pooling. Furthermore, specific mini cement units were completely freed from price and distribution controls. Although overall profitability increased substantially immediately after the introduction of partial decontrol, profits obtained through non-levy sales decreased with greater availability of cement in the market and continuously rising input costs.

To sustain an accelerating course the government subsequently introduced changes in levy obligations and retention prices. At four points in time the government simultaneously reduced levy quotas and increased retention prices. As a result, in late 1988 the levy quota was as low as 30% for units established before 1982 and the retention price had increased substantially. In addition, during 1982 and 1987 the ceiling on non-levy prices was increased occasionally. In 1987, the cement manufacturers association and the government decided that there was no further need for a maximum price ceiling.

Finally, in 1989, the industry was considered to be prepared for free market competition and all price and distribution controls were withdrawn. The system of freight pooling was abandoned and a subsidy scheme to ensure availability of cement at reasonable prices in remote and hilly regions of the country was worked out. By removing all controls in the cement sector the government hoped to accelerate growth and induce further modernization and expansion investments.

3. Statistical and Econometric Estimates

3.1 Statistical Analysis

A variety of studies on productivity growth and technological change in Indian industries has been carried out so far. Originally these studies were driven by an interest in understanding the capital vanishing phenomena in the Indian industry between 1950 and 1980. During that time, labor productivity as well as capital availability and use increased considerably, while the overall growth rate of the economy stagnated at low levels (see Ahluwalia, 1991). Concerned about the efficiency of resource use researchers started investigating productivity growth and input factor substitutions for aggregate manufacturing as well as various industries. The results of these analyses differed substantially depending on the methodology, statistical specification employed as well as on the underlying sources of data, levels of aggregation and time periods considered.

Over time more sophisticated and refined methodologies in connection with longer time series were employed to study productivity change. The contribution of total factor productivity to output growth was of primary interest to explain the continously low economic development. Partial factor productivity was investigated to better understand the importance of each factor of production and to evaluate substitution possibilities. In this context, the role of energy within the production process received increasing attention and consequently, besides the primary factors of production (capital and labor), energy and materials were added as secondary input factors into the analyses.

Total factor productivity growth (TFPG) measures the growth in gross value added (GVA) in excess of the growth of a weighted combination of the two inputs capital and labor. For measuring output in form of gross value added all intermediate inputs are deducted. Thus, gross value added only provides the value that is actually added in the production process by using the two primary inputs of production: capital and labor. Total Productivity Growth, in contrast, relates gross value of output (VO) to the four input factors capital, labor, energy and materials. Since it accounts for intermediate inputs as well as primary inputs, value of output provides the more appropriate output measure if interested in analyzing energy and material as well as capital and labor.

Commonly, three major growth accounting approaches are considered for estimating total factor productivity as well as total productivity growth: the Translog Index, the Solow Index and the Kendrick Index. The three indices differ in their complexity and the underlying economic assumptions. A detailed derivation of the three indices is provided in a survey report by Mongia and Sathaye (1998a). The Kendrick index is easy to understand in using an arithmetic aggregation scheme for the inputs. It is restrictive in that it is based on the assumption of a linear production function and in assigning constant (base year) shares in GVA (VO respectively) to the inputs. The Solow index is slightly more general in assuming a neo-classical, Cobb-Douglas, specification of the production function with constant returns to scale, perfect competition in the market and factors being rewarded their marginal products. The translog measure is based on a more complex production function associated with only a minimum numbers of assumptions. It is therefore of more general nature and provides the preferably used measure for productivity growth.

Partial factor productivity (PP) indices are reported for all input factors. They are obtained by simply dividing the value figure for each factor by the gross value of output or by the gross value added respectively. Partial factor productivity growth indicates how much output changes in relation to a fixed amount of each single input. It measures how "productive" a factor is. The inverse means how much of a factor has to be used to produce a specific amount of output - it measures the factor intensity of production. Changes over time indicate a shift in production towards more intensive use of one factor probably accompanied by less use of another factor. Additionally, the capital labor ratio (K-L ratio) shows how much capital per head is used in the production process and provides a rough measure of the capital intensity of production. The tradeoff between capital and labor is particularly interesting in the context of labor-intensive developing countries, like India, that have put the emphasis on capital-intensive industries in its early development stages in order to improve the overall economic situation.

Considering capital and labor productivity one should keep in mind that conceptually, in situations where capital intensity is increasing over time, the analysis of partial productivity changes may overstate the increase in labor productivity and understate the increase in capital productivity (Ahluwalia, 1991). With rising capital/labor ratio resources may shift from labor to the use of capital. Due to this shift, the measured increase in labor productivity may be larger than the pure increase in the productivity component (i.e. the change that is solely due to learning, learning-by-doing, improvement of skills, experience etc.). Similarly, the increase in pure capital productivity may be higher than the measured increase.

The next section will give an overview of previous studies that have been conducted on productivity changes in the cement industry. Thereafter, in the following section, we develop our own estimates for both total and partial productivity using a consistent theoretical and empirical framework.

3.1.1 Previous Studies

Previous results for statistical estimates of total factor productivity using the Translog, Solow and/or Kendrick index as well as measures of partial factor productivity and production functions for the cement industry are given in Appendix C. Figures 3.1 - 3.4

display both the historical as well as our own estimates graphically. The graphical presentation allows to immediately realize the large differences in the estimates obtained by researchers for various points of time. The overview draws on Mongia and Sathaye (1998a).

3.1.1.1 Partial Productivity

Capital Productivity

Partial productivity growth estimates for capital are presented in Figure 3.1. The estimates for the different time periods range widely from positive numbers to very negative ones. Sawhney is the only author reporting positive capital productivity growth at 1.5% for his entire study period (1950-61). Gupta receives considerable positive growth at 8.7% for a subperiod of his time series (1958-65). While his entire time period estimate (1946-65) results in slightly negative growth at –0.6%, the first subperiod covering the years 1946-58 reveals stronger capital productivity decline at –2.8%.

Arya and Mehta estimate the strongest decrease in capital productivity of all studies under consideration, at –6.0%, and -5.6% respectively. Their time periods are similar to Gupta. Goldar concludes a loss in productivity for the years 1960-70 at –0.4% similar to the results from Gupta’s study. Likewise, the estimates of Ahluwalia and Arora are very close. While Ahluwalia investigates a 25 year period from 1960 to 1985, Arora considers a subperiod from 1973-81. Productivity declines at –1.4% in Ahluwalia’s and at –1.7% in Arora’s study.

Labor Productivity

Historical estimates reveal by and large positive development for labor productivity for the various time periods. Sawhney estimates a strong productivity increase of 7.3% on average between 1950-61. For a similar time range (1946-65), Gupta points out an increase of 2.5%, while Mehta (1953-64) concludes an average productivity loss of –1.6%. For labor productivity Arora's results differ substantially from Ahluwalia's estimates. For the period 1973-81, Arora indicates a decline in labor productivity of –2.3%. For 1960-85, Ahluwalia, however, reports an increase by 1.3%. Figure 3.2 provides a summary overview of historical estimates.

Capital-Labor Ratio

The overall trend of increasing labor productivity accompanied by declining capital productivity to some extent results from a process of capital deepening. Capital deepening in the Indian cement sector is confirmed in most studies by growing capital labor ratios (Figure 3.3). Both Goldar and Ahluwalia conclude a modest increase in the capital labor ratio over time at 3.0% and 2.7% for the time periods 1960-70 and 1960-85

Figure 3.1: Estimates of Partial Productivity Growth: Capital

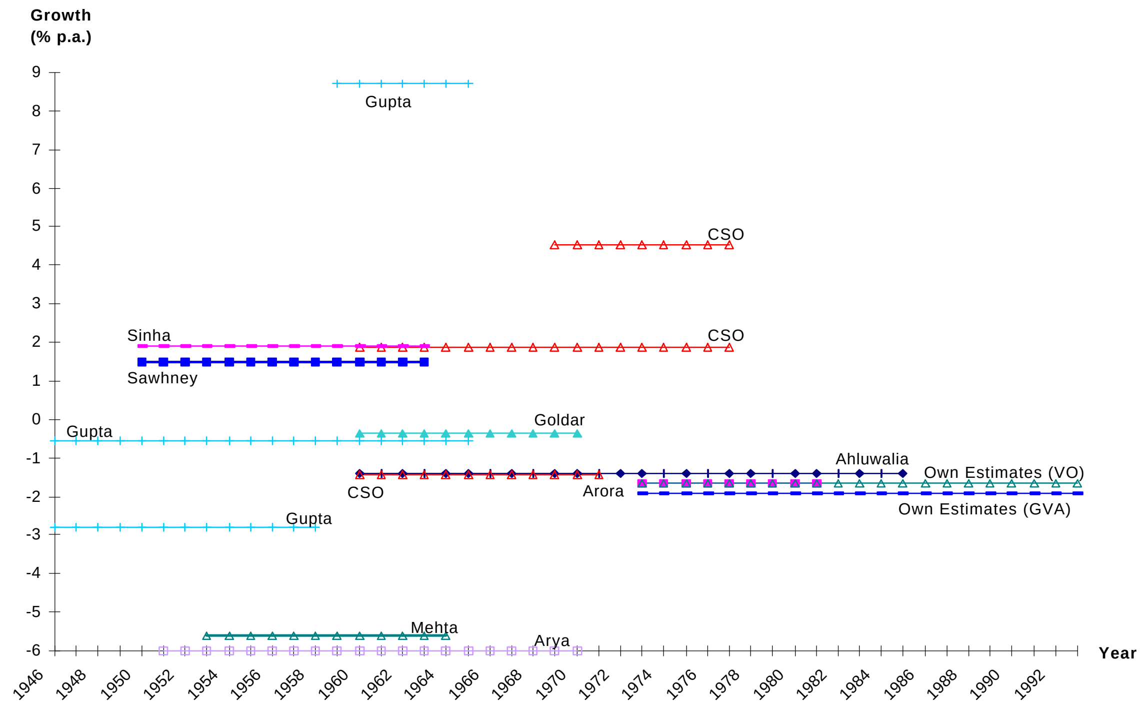


Figure 3.2: Estimates of Partial Productivity Growth: Labor

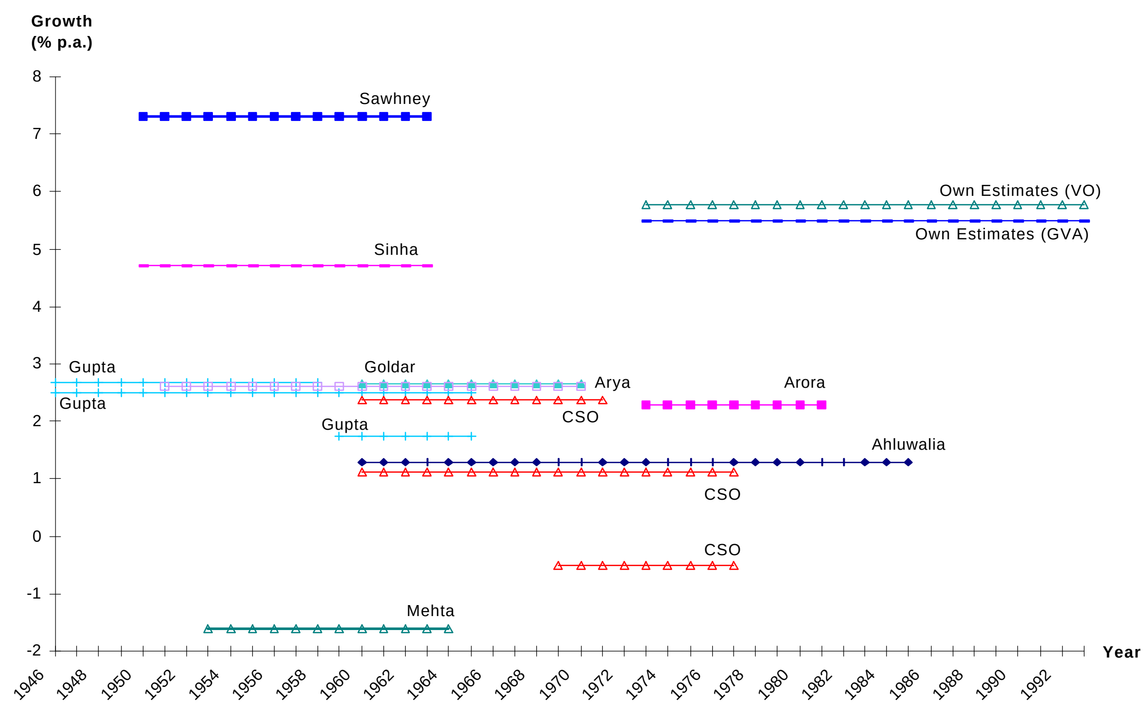


Figure 3.3: Estimates of Capital-Labor Ratio

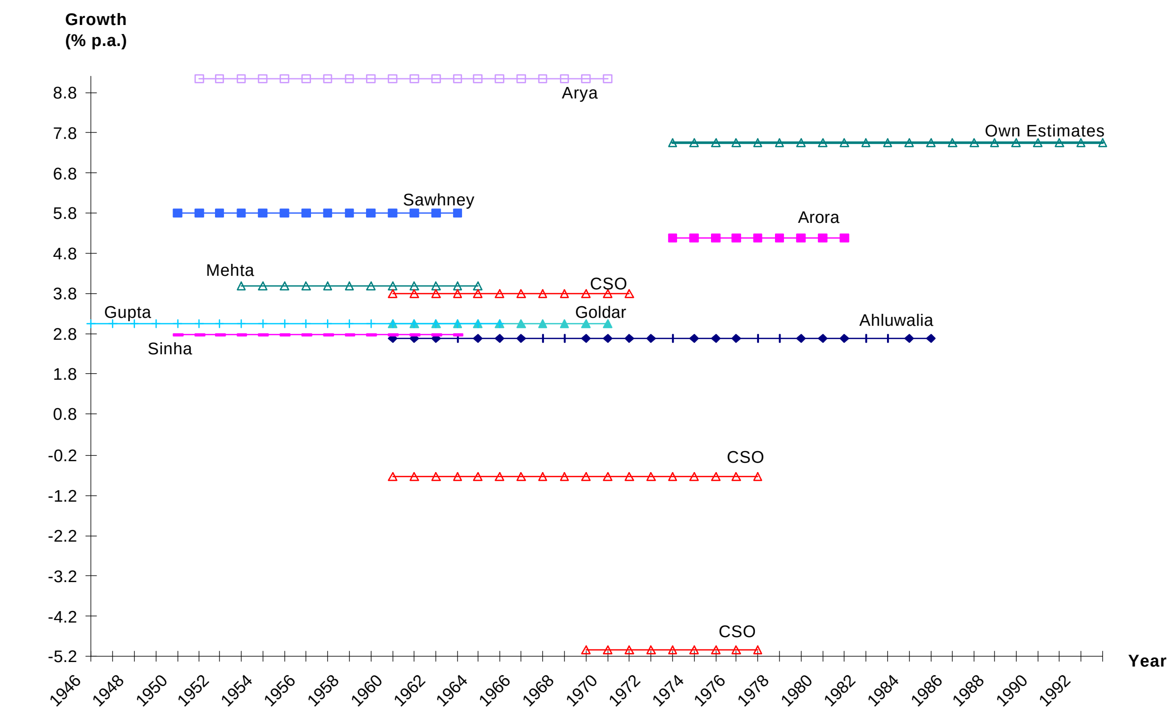
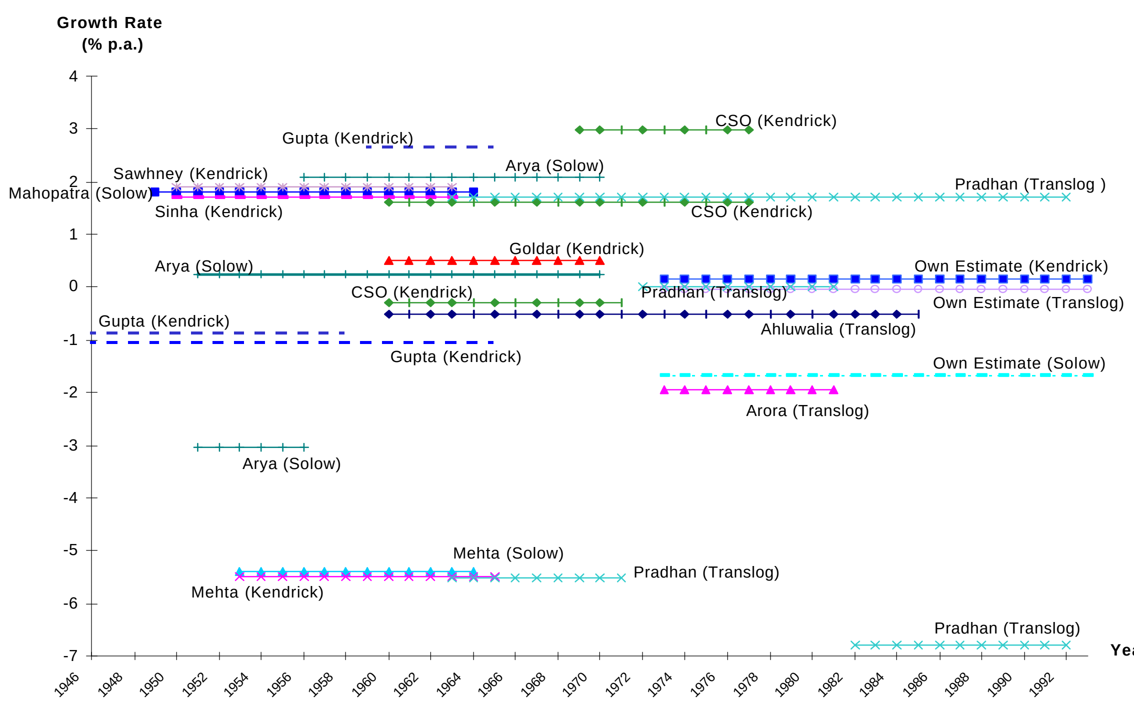


Figure 3.4: Estimates of Total Factor Productivity Growth



Note: "Own Estimates" are compound growth rates for the time period under consideration. For the translog indices they present exponential growth.

respectively. Mehta obtains a capital labor ratio of 4% for the period 1953-64, while Arora's estimate leads to a number even higher at 5.2% for the period 1973-81.

Material Productivity

Few authors consider additional inputs and productivity changes in their investigations. Exceptions to this are Gupta and Sawhney who include material inputs in their estimations and conclude very reverse results for the change in productivity. Gupta states a negative growth of material productivity at an average of –1.3% between 1946 and 1965, while Sawhney points out a positive change in productivity at 1.2% between 1950-61.

3.1.1.2 Total Factor Productivity Growth

Total factor productivity change has been investigated in various studies. The examinations result in both positive and negative development of total factor productivity depending on the time range and subperiods under consideration. Estimated productivity growth is highest in the CSO study for the subperiod 1969-77 at 3.0% p.a. and lowest for Pradhan's study, subperiod 1982-92, at –6.8% p.a.

A cluster can be observed for growth of 1% to 2% p.a. for various time periods and different indices. Furthermore, most studies considering more recent time periods seem to reveal negative productivity development in the cement sector. Besides that, no clear pattern can be identified. As mentioned above aside from the time period the study results vary substantially with the underlying data and methodology employed.

3.1.2 Own Estimates

In this section we present in detail our own estimates for both total and partial productivity. We develop the Translog, Solow and Kendrick index using a consistent theoretical and empirical framework. With the recognition of energy as a critical factor for economic growth and the special emphasis on energy use within this report, we explicitly account for energy in using a four factor input approach (K,L,E,M) in our analysis. As a comparison, we additionally state the results obtained from the two input factor model. Data has been compiled for the years 1973-93 from the Annual Survey of Industries, Government of India (various years). The methodology is explained in detail in Mongia and Sathaye (1998).

3.1.2.1 Partial Productivity

Table 3.1 gives the partial productivity growth for the various inputs based on both value of output and gross value added. The table indicates the growth rate over the whole time period as well as split up by different time ranges within this period. Growth rates for the time periods are calculated as compound growth rates and time trends. This is to be in accordance with existing growth estimates conducted by various authors and presented in

Section 3.1.1. above. Figure 3.5 displays the partial productivity of capital, labor, energy and material in relation to the value of output.

Table 3.1 Partial Productivity Growth **(selected time periods, per cent p.a.)**

Growth	Capital VO / K	Labor VO / L	Energy VO / E	Material VO / M	K / L ratio K / L	Capital GVA / K	Labor GVA / L
1973-93	-1.65	5.77	0.08	2.21	7.54	-1.91	5.49
1973-83	-4.95	2.97	-0.50	-0.87	8.32	-2.51	5.60
1983-91	4.16	12.13	1.10	7.05	7.65	6.36	14.50
1991-93	-7.34	-4.27	-1.03	-1.06	3.32	-26.81	-24.38
Trend Rate 1973-93	-3.53	6.56	-0.37	2.27	10.09	-2.65	7.44

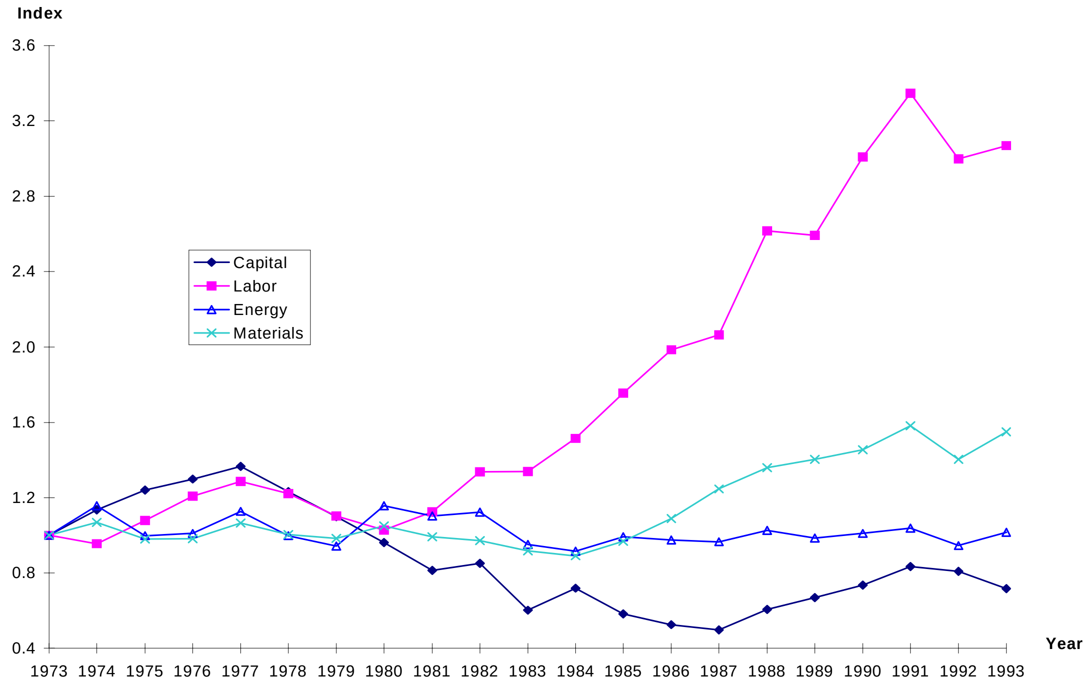
Note: Compound Growth; Trend Rate calculated as semi-logarithmic time trend, significant on 5% level.

The table as well as the figure support significant changes in average productivity in the early 1980s and again in 1991. The first ten years of the time period under consideration (1973-83) show fluctuating patterns. Labor and capital productivity first increase and then fall at similar rates. In 1980, a turnaround in labor productivity can be observed while capital productivity further decreases. Energy and material productivity grow and fall at similar rates during that period. The following period, 1983-91, substantiates a period of progress with positive factor productivity growth for all factors. Yet, a sharp drop in productivity interrupts the overall upward trend in 1991. Most factors indicate a positive turn from 1992 on but for drawing further conclusion the time horizon would need to be expanded to include more recent trends. Over the whole time period 1973-93, factor productivity was increasing for labor and material and decreasing for capital and slightly for energy.

Capital and labor productivity changes are of particular interest. Labor productivity increases over the whole time period as well as for different subperiods except the years following 1991. Labor productivity growth is by far highest at 12.1% in the period of overall progress in the cement sector between 1983 and 1991. Conversely, capital productivity shows an overall decreasing trend at –3.5% between 1973 and 1993. The downward trend is continual in the late 1970s and early 1980s. In accordance with the overall trend, capital productivity increases at 4.2% between 1983 and 1991 followed by a modest drop after 1991. The increase in labor productivity is to some extent the result of the process of capital deepening, the increasing use of capital per head, indicated by a high growth in the capital labor ratio at 10.1%. Resources have shifted from labor to the use of capital over time.

The examination of capital and labor in relation to gross value added rather than gross value of output confirms the results for capital and labor productivity. Due to an extraordinary drop in GVA in 1991 losses in productivity of capital and labor in relation to GVA are of much higher values than in relation to VO. However, the results are of similar nature in terms of direction and size of change.

Figure 3.5: Index of Partial Productivity (KLEM and Value of Output)
based on 1973-74 constant values



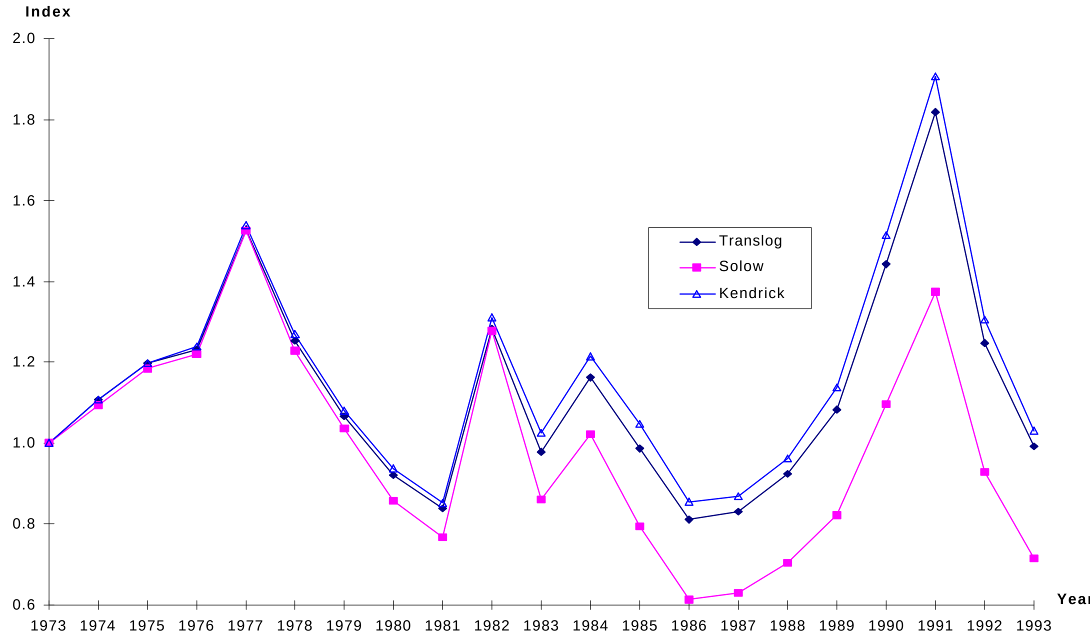
Unlike capital and labor, energy and material follow a very similar path over the whole time range. They show slightly decreasing growth in the first ten years of the time period considered (1973-83). Between 1983 and 1991, however, they progress substantially with material productivity rising at 7.05% and energy productivity at 1.1%. Thereafter, following 1991, both energy and material productivity fall down to negative productivity development again.

3.1.2.2 Total Factor Productivity

Total factor productivity relates the input factors capital and labor to gross value added. It measures the growth in gross value added (GVA) that can not be explained by the growth of a weighted combination of the two inputs capital and labor.

Figure 3.6 shows the development of total factor productivity as measured by the Kendrick, Solow and Translog Indices over time. In addition, Table 3.2 gives total factor productivity growth for different time periods. The growth rates for the Kendrick and the Solow indices are estimated as compound growth rates. The Translog index, however, is based on the assumption of exponential growth due to its logarithmic, non-linear nature.

Figure 3.6: Index of Total Factor Productivity
based on 1973-74 constant values



The three indices are related in their patterns. The Translog index fluctuates in between the Kendrick and the Solow index. The division into three subperiods reveals similar behavior of total factor productivity to partial productivity. The period 1973-1983 on average shows negative growth for the Translog and Solow index (Translog: -0.22%, Solow: -1.49%) and minimal positive growth at 0.16% for the Kendrick index. In contrast, the second period, 1981-93, gives very positive factor productivity growth at 7.75% (Translog), 6.04% (Solow) and 8.04% (Kendrick) with a strong peak for all indices in 1991. Following this peak, total factor productivity decreases rapidly at high rates of 26.42% to 30.23%.

Table 3.2: Total Factor Productivity Growth
(selected time periods, per cent p.a.)

Growth	Translog	Solow	Kendrick
1973-93	-0.03	-1.66	0.16
1973-83	-0.22	-1.49	0.26
1983-91	7.75	6.04	8.04
1991-93	-30.23	-27.90	-26.42
Time Trend			
1973-93	0.09	-1.82	0.38

Note: Translog: Exponential Growth; Solow, Kendrick: Compound Growth.
Trend Rate calculated as semi-logarithmic time trend, significant on 5% level.

3.1.2.3 Total Productivity

Total productivity measures the growth in gross value of output in excess of the growth of a weighted combination of the inputs capital, labor, energy and material. As with total factor productivity we consider three different indices for measuring total productivity.

Table 3.3 and Figure 3.7 present the growth of the three indices and their evolution over time. The patterns differ slightly from total factor productivity estimates due to the more modest development of value of output over time compared to the development of gross value added. Figure 3.7 best supports the division into the three subperiods (1973-83, 1983-91 and 1991-93). All three indices show fluctuating behavior for the first time period, accounting for a decrease in total productivity of –1.66% (Translog), -2.50 (Solow) and –1.47 (Kendrick). Reaching a low point in 1983, total productivity increases steadily thereafter. Total productivity growth of around 4.8% for all indices supports the notion of overall progress in the cement industry between 1983 and 1991. Following a peak in 1991, total productivity drops in 1992 and then again recovers slightly.

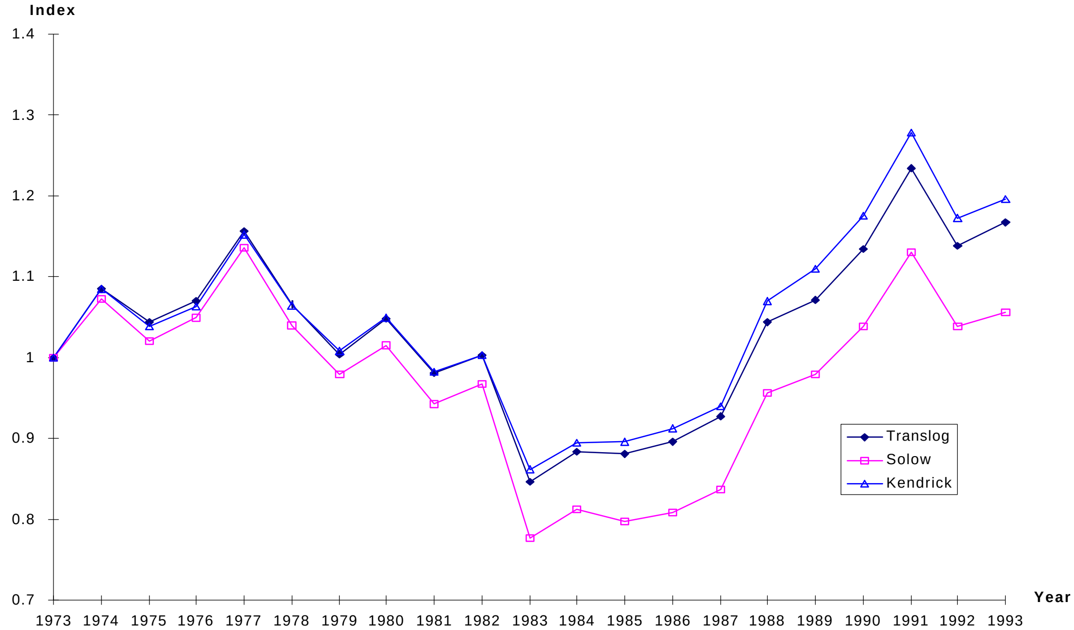
For the whole time period under consideration two indices, Translog and Kendrick, indicate a slight increase in total productivity of 0.26% and 0.47%. The Solow index shows a decrease of –0.28% p.a. As explained above this growth is driven by a very positive development in the mid 1980s to the beginning of the 1990s which offsets the losses in the remaining years. To see why these three distinctive time periods can be extracted and which factors underlie the specific development, Section 3.3 will in more detail discuss the results in the context of overall economic and policy changes at specific points of time.

Table 3.3: Total Productivity Growth
(selected time periods, per cent p.a.)

Growth	Translog	Solow	Kendrick
1973-93	0.77	0.28	0.90
1973-83	-1.66	-2.50	-1.47
1983-91	4.71	4.80	5.04
1991-93	-2.84	-3.32	-3.28
Time Trend			
1973-93	0.26	-0.28	0.47

Note: Translog: Exponential Growth; Solow, Kendrick: Compound Growth.
Trend Rate calculated as semi-logarithmic time trend, significant on 5% level.

Figure 3.7: Index of Total Productivity
based on 1973-74 constant values



Decomposition of Growth in Value of Output

A very insightful way of looking at growth in output is to decompose growth into the contribution of factor input changes and total productivity growth. Generally, growth in production is two-folded consisting of increased use of inputs and some additional change (gain or loss) in productivity. As mentioned growth in productivity thereby includes technological change, learning, education, organization and management improvements etc. The two-folded base of growth in output can naturally imply that growth in output is accompanied by increase in factor input and decrease in productivity, by decrease in factor input and increase in productivity or by increase in both factor input and productivity. Table 3.4 presents the decomposition results for our study period and the subperiods identified above.

Table 3.4: Decomposition of Growth in Value of Output

Year	Growth (%) in Value of Output	Labor Input	Capital Input	Material Input	Energy Input	Total Input	Total Productivity
1973-93	**8.69**	**0.23**	**2.89**	**2.57**	**2.22**	**7.92**	**0.77**
1973-83	6.35	0.30	3.05	3.04	1.61	8.01	-1.66
1983-91	13.68	0.15	2.82	2.54	3.46	8.97	4.71
1991-93	0.43	0.22	2.34	0.37	0.33	3.27	-2.84

Table 3.4 shows that overall output in the cement sector measured as average exponential growth of gross output followed a quite positive trend growing at 8.69% over the period 1973-93. However, the decomposition reveals that this positive development is mainly due

to increased use of factor inputs (7.92% growth in factor inputs). Productivity growth over the same time period only contributes 0.77%. The same is true for the subperiod of progress, 1983-91. Increases in output contribute 8.97% to the increase in output of 13.68% during that period. Productivity gain reaches its highest share accounting for more than a third, 4.71%, of output growth.

The periods 1973-83 and 1991-93 show less positive development. Productivity decreases at –1.66% (-2.84% respectively) during these periods implying that output growth is solely driven by the increased use of factor inputs. Total inputs contribute 8.01% in the earlier period, about the same amount they contribute in the period of progress. Productivity growth, however, is negative so that overall output in the early period is lower. The last period (1991-93) gives small increases in the use of factor inputs as well as a significant decline in productivity resulting in almost stagnating output (0.43%).

3.2 Econometric Analysis

The accounting framework employed for the derivation of total and total factor productivities does not explain why factor demand changes over time. However, understanding substitution processes between input factors and the effects of factor price changes on input use is crucially important for determining the rate and direction of technological change and thus productivity growth. Few researchers so far have tried to tackle this issue in econometrically estimating production or dual cost functions and concluding patterns and relationships between input factors.

3.2.1 Previous Studies

Arya (1983) studied technological and productivity changes for 15 cement manufacturing companies. Using data from annual reports of the companies for the years 1956-72 he estimates Cobb-Douglas production functions. The trend rates of growth show wide variation across his sample and fall in the range of 0.8% to 6.8% p.a. Capital intensity during that time period increases at an average rate of 2.8% p.a. for the sample group.

Mehta (1980) also estimates Cobb Douglas production functions for some energy-intensive industries including the cement industry. His sample period encompasses the years 1953 to 1965. He finds evidence of capital deepening in the production process but could not conclude any clear trend regarding efficiency improvements. Productivity in the cement sector for his time period grows at 6.1%.

3.2.2 Own Estimates

Our results for the econometric estimation of productivity change and patterns of input substitution are received from both the statistical analysis and from estimating a translog cost function approach with four input factors: capital, labor, energy and material. For a detailed presentation of the economic framework, the specifications and the estimates see

Roy et al. (1999). The following tables extract from their results and present the most important and most interesting findings to our analysis.

Our analysis focuses on the causes and effects of changes of factor inputs with particular emphasis on energy use. Accordingly, energy prices and energy price changes over time play a dominant role. Therefore, Table 3.5 presents the elasticities of the cost shares[2] for each input with respect to changes only in energy prices. The technical bias parameter is reported for all factor inputs and is crucially important for understanding direction and rate of technological change. It indicates which of the factors have been substantially made use of in the process of technological change.

Table 3.5: Estimated Parameters for the Translog Cost Function Approach

Parameter	b_{me}	b_{le}	b_{ke}	b_{ee}	b_{mt}	b_{lt}	b_{kt}	b_{et}	b_{tt}
	-0.181	0.018	0.123	0.040	-0.004	-0.004	0.003	0.005	-0.002
t-value	(-3.672)	(1.353)	(3.785)	(1.393)	(-2.930)	(-9.732)	(2.521)	(7.265)	(-0.552)

b_{ij}= elasticity of share of i input with respect to the change in the price of jth input
b_{it}= technical bias parameter

Regarding the cost share elasticities the table shows that the cost shares of capital, labor and energy increase with rising energy prices while the cost shares of material decreases with rising energy prices. However, the increase in labor and energy are insignificant. The parameter b_{tt} a slight but insignificant acceleration of technical change over time. Economically, a constant technical change parameter would mean a downward or upward shift of the production function to be constant over time, or in other words a constant autonomous increase/decrease in production independent of inputs. As shown in the previous section productivity in the cement sector has been increasing in the past. Thus, a technical change parameter b_{tt} equal to zero would indicate that this advance has been quite stable over time. This hypothesis, however, can not be sustained from the analyses of the previous chapter. Changes in productivity usually affect all input factors differently. The technological change bias parameters, b_{it}, indicate a significant energy and capital using bias. At the same time technological change is significantly material and labor saving (Table 3.6).

Table 3.6: Technical Change Bias

	Material	Labor	Energy	Capital
Technical Change	saving	saving	using	using

For the analysis of patterns of substitution and effects of price changes on the immediate use of input factors the own and cross price elasticities are of particular interest. Price elasticities show the extent to which the input of one factor changes in response to a price change of one other or the same input factor. Own price elasticities have to be negative by theory. A price increase for a normal good leads to reduced demand for this particular good. A positive cross price elasticity indicates a substitutional relationship between the

[2] Cost shares are defined as factor input costs over total input costs (sum of capital, labor, energy and material costs).

two input factors considered. It gives an increase in factor demand of factor i due to a decrease in factor price j which itself leads to a reduction in demand for factor j.

Table 3.7: Price Elasticities

	Price Elasticity		Price Elasticity		Price Elasticity		Price Elasticity
KK	-0.252	LK	0.662	EK	0.567	MK	-0.415
KL	0.369	LL	-1.206	EL	0.148	ML	0.007
KE	1.085	LE	0.507	EE	-0.568	ME	-0.097
KM	-1.202	LM	0.037	EM	-0.146	MM	0.505

The price elasticities are shown in Table 3.7. Except for material input, all own price elasticities are negative as required by theory. Among the own price elasticities, labor price elasticity is highest with –1.2, followed by energy price elasticity, -0.6 and capital price elasticity, -0.3. Cross price elasticities indicate substitutional relationship between all input factors except capital and material, and energy and material inputs. Thus, a rise in, for example, energy prices will lead to increased use of capital and to a lesser extent of labor inputs to substitute for the more expensive energy input. At the same time material input will decrease. Among the input factors, the relationships between capital and material, and between capital and energy are most elastic. A 10% increase in energy price would lead to a 11% increase in capital input while at the same time energy use would decrease by 5.7%. The other way round, a 10% increase in capital price would lead to a 5.7% increase in energy use while capital use at the same time would decrease by 2.5%.

Table 3.8: Elasticities of Substitution - Qualitative Overview

	Energy	Labor	Capital
Material	complements	substitutes	complements
Energy		substitutes	substitutes
Labor			substitutes

3.3 Discussion

The results described in the previous section need to be set in context of actual changes in policies within the cement sector and the Indian economy over the last 20 years to better understand the factors driving technological change and productivity growth.

As shown above, productivity in the cement sector has been increasing over time. Productivity gains were strongest in the 1980s following a major shift towards decontrol in the cement sector. The split-up of the time period into three subperiods (1973-83, 1983-91 and 1991-93) is in accordance with structural and policy changes in the sector. Two major policy changes took place in 1982 and 1989. The subperiods are chosen under the aspect that policy changes do not show immediate effects on the sector but need some time to become integrated into decision and production behavior of individual firms.

The first subperiod covers the period of total control in the cement sector. Price and distribution had been controlled since 1951, furthermore industrial licensing and freight pooling was applied to cement production. During our study period within the era of total control (1973-83) productivity decreased by –1.7%. Output growth (6.4%) was mainly driven by increased use of input factors such as capital and material. Energy use also played a major role. Yet, output growth was not enough to satisfy growth in demand and the sector experienced a difficult time.

Two main cost factors, energy and transportation costs, imposed substantial burden on the industries. Costs for fuel, power, transportation as well as wages increased substantially over time mostly due to government regulations. Furthermore, as mentioned above coal was not easily available due to transportation constraints, fell short of assigned quotas and was of low quality. The mostly privately structured business houses could not retrieve profitable returns and profit margins dwindled significantly. Therefore, urgently needed investments into capacity expansion, as well as modernization and upgradation of the industry were not carried out.

Due to sustained slow development in the cement industry the government increased retention prices several times. Finally, in 1982 the government introduced a system of partial decontrol. A levy quota in connection with a uniform retention price was imposed on sales to government and small house builders. The new policy provided a major liberalization of the industry and led to significant progress in terms of capacity expansion and increased production. For the first time the industry was able to receive adequate returns to investments. Profit margins increased stimulating further investments in both expansion and modernization of the industry. Output grew at an average of 13.7% p.a. accompanied by substantial gains in productivity. Between 1983 and 1991 productivity increased continuously at 4.7%.

Energy input at the same time rose considerably. The decomposition analysis reveals that between 1983-91 of all input factors energy contributed most to output growth supporting the significant relevance of energy as an input to cement production. Energy productivity during that time period increased at the lowest rate amongst the input factors. While substantial savings in labor, material and capital can be observed, energy input in relation to output remains quite stagnant. This is almost surprising considering that most of the newly added cement plants made use of more modern and efficient technologies and processes such as the more energy efficient dry process for clinker production. It indicates that efficiency improvements are not adequately reflected in economic measures so that potential gains could not be economically appropriated.

While the industry as a whole was progressing following the changes in price and distribution policy, the problems regarding the infrastructural constraints remained severe. Transportation capacity for either coal or cement did not increase and consequently both high input costs and scarcity of inputs pressured the industry. Many smaller cement plants were set up during that time in order to avoid high transportation costs as well as to reduce capital costs and increase regional development. Thereby, remote areas could be served at reasonable prices within short time periods. Small and mini plants, however, are generally less efficient in terms of input, particularly energy, use. Energy efficient technology, such as pre-stage kilns and waste heat recovery/utilization, cannot economically be provided due to the small scale of production.

To sustain the positive development of the sector and to further spur investment into modernization and expansion, the government decided in 1989 to withdraw all price and distribution controls in the cement sector. Effects of this liberalization policy might partly be captured in the time period until 1991. The immediate effects are reflected in a strong increase in output and productivity until 1991. Price escalation became very steep in early 1990 (Sinha, 1997) allowing the industry to receive adequate returns to their investments. These gains, however, were not distributed evenly. Due to the abolishment of freight equalization, there was a wide divergence in input costs with varying rates of sales tax and transportation resulting in the prices of cement varying widely from region to region. Thus, some industries, mostly large plants in central areas, were doing relatively better than others.

In the early 1990s, production levels stagnated and productivity decreased significantly at -2.8% (between 1991-93). Suddenly, capital inputs present the driving force replacing energy as the driving force in the previous period of progress. This indicates that firms were still willing to invest to maintain the positive development. Increases in capital and investment are reflected in expansion of installed capacity from 66 Mt (1991) to 76.8 Mt (1993). Since production did not increase accordingly this led to a decline of capacity utilization by 5%. The main reason for the shortfall was recession conditions in the economy and a sharp decline in the off-take by the public sector. Growth in construction activity (GVA in construction) fell sharply from over 11% to only 2%. It is obvious that demand placed a sudden constraint on the expansion of cement production. The industry was ready to meet higher demand by increasing production. Unfortunately, export of cement did not present a feasible alternative due to high transport costs, congestions and berthing delays at ports, lack of storage space and facilities for export in bulk, non-availability of high quality paper-bags for transportation etc. (Sinha, 1997)

In addition, a high excise duty on cement products was kept probably in view of the improved financial performance of the sector in the previous years. Coal quality deteriorated further and purchases of high grade coal from open international markets under high concessional import duty had to be taken. Thus, once again the industry suffered from difficult conditions and profit margins even of big companies eroded seriously. Consequently, investment in new and existing capacities slowed down.

Technological change in the cement sector was accompanied by an energy using bias. This means that, independent of prices, over time the trend was towards the increased relative use of energy, as reflected for example in the conversion from manual transportation to the use of electrical conveyer belts etc. The development of energy prices is of particular interest in an energy-intensive industry like the cement industry. An increase in energy prices through policy or world market changes would impose relatively higher costs through the nature of the industry's technological progress towards the use of energy. Technological change and productivity growth would therefore most likely be reduced.

Moreover, inter-input substitution possibilities are weak. With few exceptions, the estimated elasticities point to little substitution possibilities.

4. Future Development of the Cement Sector

4.1 Ongoing Changes in the Cement Industry

Ambitious modernization and expansion programs are currently underway in the Indian cement industry. Through adoption of modern technology and equipment, input substitution, output modification, organizational changes as well as other process specific measures India is trying to increase output at the same time as to improve efficiency, conserve energy and control pollution.

Process conversion presents a notable example of energy conservation in the Indian cement history. Over the last 30 years, the more energy-intensive wet process of cement production has been virtually phased out.

Other process specific measures that have increasingly found application in the Indian cement industry include multi-stage suspension preheaters, precalciners, cyclone designs of kilns, and improved burners. Most of these measures are related to the energy-intensive pyroprocessing step in cement production, while fewer measures are effective for the grinding and drying steps. However, the use of more advanced grinding mills, such as roller or high pressure roller mills instead of rod and ball mills also shows substantial power savings potentials. (Karwa, 1998)

Due to frequent power cuts causing damage to plant operation and viability and due to high power the cement industry has started installing captive power generating units. These power generation systems are based on cogeneration and/or waste heat recovery and lead to substantial savings in terms of energy use and costs. In fact, cogeneration of power using waste heat is a very attractive proposition for energy conservation world wide which the cement industry (with its high share of waste heat resulting from the high temperature sintering process of cement making) is well suited for.

Unlike in most other countries, cogeneration has not yet been much exploited by Indian cement manufacturers. However, installed capacity of captive power that might be based on cogeneration has steadily been increasing (accounting for about 19% of electricity consumption in 1993-94, Confederation of Indian Industry, 1995) leading to more efficient and stable clinker production as well as laying the foundation for higher and more continuos capacity utilization of cement plants. Additionally, waste heat utilization has become more common for use in raw material drying substantially reducing energy requirements.

Table 4.1 presents major cement projects in terms of both additions to existing units as well as new units that are proposed or already under implementation as of 1997. The 19 units that are under implementation will add another 20.6 million tonnes of capacity.

Despite a few larger units with capacity of 2.6 and 2 million tonnes most of these new units have a capacity below 1.5 million tonnes. Another 35 units have been proposed for capacity addition. 26 of these units are proposed with a capacity below 1.5 million tonnes. Only two big units are planned with capacity of 2.7 and 3 million tonnes capacity respectively. All units are spread out over the country.

Together, proposed units and units under implementation would account for an additional 66.1 million tonnes of capacity for cement production in India. Considering the presently installed capacity of 105.2 million tonnes this presents a major expansion objective that will ensure sufficient supply for the home market and potentials for exports.

Table 4.1: Expansion of Cement Manufacturing Capacities

No. of Units	Units			
	Capacity (Mt)	New	Expansion	Status
19	20.6	14	5	Under implementation
35	45.4	30	5	Proposed
Source: Karwa (1998).				

We estimated the future demand of cement by regressing cement production on a) GDP_{total}, b) $GDP_{industry}$ and c) $GDP_{construction}$. As mentioned in Section 2.3 construction activities are the main driver of cement demand which enhances cement production. With little foreign trade cement demand is taken approximately equal to cement production. GDP_{total} is assumed to increase at its 1990-95 trend rate of 5.4% p.a., while $GDP_{industry}$ is assumed to grow at 6.2% p.a. (1990-95 trend rate). $GDP_{construction}$ has been growing at 4.4% p.a. between 1992 and 1995. For the analysis it is assumed to grow at an average 5.6% between 1992 and 1997, and 6% thereafter (Das and Kandpal, 1997). Projections based on these assumptions as well as the average of the production estimates are given in Table 4.2. Detailed regression results are presented in Appendix D.

Table 4.2: Projected Cement Demand **(Mt/annum)**

	Cement Demand (Mt/annum) based on			
Year	GDP_{total}	$GDP_{industry}$	$GDP_{construction}$	Average
2001	103.0	107.6	106.2	105.6
2006	139.5	148.7	150.8	146.3
2011	186.9	204.2	210.4	200.5

Taking the average of the estimates, cement demand (and thus production) is expected to increase by about 39% to slightly over 100 Mt p.a. by the year 2001. It will further increase at an average rate of 6.5% p.a. to 146.3 Mt p.a. in 2006 and to almost twice the amount of 2001, 200.5 Mt p.a., by the year 2011, growing at a slightly lower rate of 6.3% p.a. Considering the expansion plans, these estimates are to be taken as upper boundaries.

4.2 Potentials for Energy Efficiency Improvements

4.2.1 India versus Best Practice

Energy savings in the cement sector are possible by energy efficiency improvement and by increased use of blended cements, thereby reducing the demand for energy-intensive clinker. We first identify energy savings potentials that can be achieved by efficiency improvements alone. For this we compare specific energy consumption in Indian cement plants with specific energy consumption in plants using world best technology leaving the structural composition of cement production in India unchanged. Table 4.3 presents the savings potentials for Indian dry process plants as well as for the average plant. In a second step we identify the structural change that would lead to additional energy savings. These structural savings as well as the cumulative savings and cumulative best practice energy consumption are given in Table 4.4.

<u>Efficiency Improvement</u>

Best technology specific energy consumption is calculated based on a dry process short kiln with a 4-stage preheater consuming 3.05 GJ_{fuels}/t clinker and 0.36 $GJ_{electricity}$/t ground clinker. For grinding and blending of additives an additional 0.24 $GJ_{electricity}$/t additive is assumed. (Worrell et al., 1995)

Comparing best technology energy consumption to energy consumption in Indian dry process plants (employing preheaters) reveals savings potentials of 10-15%. In relation to other energy-intensive industries, such as iron and steel where energy savings potentials of 50% were identified (Schumacher and Sathaye, 1998), the gap in the cement sector turns out to be much lower. This supports our findings that Indian dry process cement plants today are already quite modern and energy efficient. The comparison of best technology energy consumption to average energy consumption in Indian plants reveals a higher savings potential of 24-35%, more than twice the savings potential of dry process plants. This confirms the inefficiencies existing in wet and semi-dry plants.

Table 4.3: Specific Energy Consumption: India vs. Best Practice

		1991	1992	1993
India				
Dry Process Plant[*]				
Electricity SEC	GJ/t cement	0.43	0.41	0.40
Fuel SEC	GJ/t cement	3.02	2.89	3.00
Total SEC (final)	GJ/t cement	3.45	3.30	3.40
Average of Plants[**]				
Electricity SEC	GJ/t cement	0.32	0.43	0.42
Fuel SEC	GJ/t cement	3.77	4.03	3.58
Total SEC (final)	GJ/t cement	4.09	4.46	4.00
Best Practice[***]				
Electricity SEC[****]	GJ/t cement	0.34	0.34	0.35
Fuel SEC[*****]	GJ/t cement	2.60	2.57	2.71
Total SEC (final)	GJ/t cement	2.94	2.91	3.06
Savings Potential				
Compared to Dry Process Plant				
Electricity SEC	%	20.4%	17.9%	14.3%
Fuel SEC	%	13.8%	10.9%	9.5%
Total SEC (final)	%	14.6%	11.7%	10.1%
Compared to Average of Plants				
Electricity SEC	%	-5.8%	20.5%	17.7%
Fuel SEC	%	31.0%	36.2%	24.2%
Total SEC (final)	%	28.1%	34.7%	23.5%
Clinker-Cement Ratio	Ratio	0.84	0.83	0.88

[*]Source: Karwa, 1998.
[**]Calculated from TERI, 1996/97 assuming heating values as given in Appendix H.
[***]Based on a dry process short kiln with a 4-stage preheater. (Worrell et al., 1995)
[****]Calculated assuming electricity consumption of 0.36 GJ_e/t ground clinker and an additional 0.24 GJ_e/t additive for grinding and blending of additives. (Worrell et al., 1995)
[*****]Calculated assuming energy consumption of 3.05 GJ/t clinker corrected for the amount of energy used to blend the cement: 0.75 GJ/t blast furnace slag for drying of blast furnace slag and none for drying of fly-ash. (Worrell et al., 1995) Portland Slag Cement (PSC) holds a share of 9% in total cement production; it is assumed to be composed of blast furnace slag to 50%.

Structural Change

While above savings potentials are calculated based on efficiency improvement alone, additional savings are possible through increased use of additives in cement making (Worrell et al., 1995). Blending cement with additives reduces the consumption of energy-intensive clinker. However, savings potentials are very much determined by indigenous availability of resources commonly used to blend cement, such as blast furnace slags, fly-ash, natural pozzolanes, etc. Assumed best practice compositions of cement types are presented in Appendix E. Energy savings potentials from structural change are two-fold. First, changes in output mix towards increased production of Portland Slag Cement reduces energy consumption because less clinker is needed in Portland Slag Cement production. Second, changes in input mix of Portland Slag Cement towards higher share of blast furnace slag in relation to clinker lead to further reduction in energy demand.

For Portland Slag Cement (PSC) we assume that all slags are available for cement making. The calculation of available slags is based on the pig iron production and an assumed slag production of 200 kg/t pig iron for ‘best practice’ blast furnaces. The actual slag production is estimated on the basis of the iron ore consumption relative to the pig iron production, and multiplying this factor with the ‘best practice’ slag production. Fly ashes are produced by the burning of coal in electric power generation, and production depends on the ash content of the coals used. We assume that the coal has an average ash content of 33% (Das, Mehra et al., 1993). We also assume that the fly-ash is 80% of total ash produced and that 50% of the fly-ash has characteristics suitable for cement blending. (Worrell et al., 1995) Based on this information, we determine the optimal penetration of different types of cement at 25.4% Ordinary Portland Cement, 61.1% Portland Pozzolanic Cement and 13.5% Portland Slag Cement.

Effects of both structural change and efficiency improvements on energy consumption and savings potentials in 1993 are summarized in Table 4.4. In accordance with other countries, the structural effects on energy savings are lower than the effects from technology improvements (Worrell et al., 1995). In India, 20% of final energy could be saved due to the two-fold effect of structural change. With a relative high abundance of blast furnace slag from the iron and steel industry, we calculate that production of Portland Slag Cement could be increased from currently 9% to 13.5% using 65% blast furnace slag, 30% clinker and 5% fillers. As a result, the clinker-cement ratio would decrease by 20% from currently 88% to 68%. With a calculated savings potential of 24% from energy efficiency improvements, the cumulative savings potential for final energy consumption amounts to 38%, equivalent to 2.46 GJ/t of cement or 89.19 PJ final energy in total. A reduction of 40% can be achieved for thermal energy consumption while the potential for electricity savings is calculated at 23%.

Table 4.4: Energy Savings Potentials in India’s Cement Industry (1993)

Effects Structural Change			**Energy Eff.**	**Cumulative Effects: Efficiency Improvement and Structural Change**			
Current C/C Ratio	Possible C/C Ratio	Savings Final Energy	Savings Final Energy	Cumulative Savings Final Energy	Resulting SEC-Fuel	Resulting SEC-Electr.	Resulting SEC-Final Energy
88%	68%	20%	24%	38%	2.14 GJ/t	0.32 GJ/t	2.46 GJ/t

It should be noted that to not confuse gains in electricity generation efficiency and in overall energy efficiency, only final energy consumption has been considered in the best practice calculation. Improvements in power generation efficiency can well be expected due to modernization and upgrading of the power sectors as well as increased establishment of onsite captive power generators. This will at least substantially reduce transmission and distribution losses. Naturally, improvement in generation efficiency will lead to lower primary specific energy consumption for the cement sector.

4.2.2 Categories for Energy Efficiency Improvement

Potentials for energy efficiency improvement build on ongoing changes in the cement sector. Besides above mentioned technology specific and structural potentials further conservation options arise, such as the complete conversion from wet to dry processes, from installation of cogeneration and waste heat recovery facilities, from improvements in input factors as well as from organizational and managerial matters. Better maintenance and monitoring of plant activity, for instance, can minimize downtime of machinery and plant, thus avoiding excess energy needed for restarting the process.

Appendix F presents in detail cost-effective energy conservation options that have been identified for the Indian cement industry. The range of possible energy savings is wide depending on the measure taken and the extent of implementation. Most options require no or negligible investments.

4.2.3 Barriers to Energy Efficiency Improvement

Although most of the measures for energy efficiency improvement (Appendix F) are cost effective and provide net benefits within a certain time period, only a few measures have been or are currently being implemented in the Indian cement industry. Barriers to energy efficiency improvement are of both general and firm/process specific nature thus occurring at the macro and micro level of the economy.

In a capital scarce country like India capital intensive industries generally focus on reducing capital costs rather than being concerned about energy inputs that hold low shares in overall input costs[3]. In 1993-94, energy costs in relation to total input costs were as low as 22.8%. In contrast energy costs in relation to production expenditure which do not capture total capital requirements accounted for 40 to 50% (Mall et al. 1992). Lack of dissemination of information on energy-efficient technologies as well as specific information on savings and benefits of energy savings further contribute to the reluctance to improve energy efficiency.

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[3] It seems useful to distinguish between different approaches to calculating input cost shares. Cost shares can be calculated based on production expenditure, on operating costs (variable costs), on total input (capital, labor, energy, and material) costs and others. The approaches mainly differ in their assumptions on capital costs. Operating costs, for example, comprise interest charges, rent paid and depreciation as costs of capital, while the total input cost approach counts fixed capital, the depreciated value of fixed assets at the end of the accounting year, as annual input costs of capital. If one is interested in activities such as retrofitting, upgradation or installation of energy savings devices energy input costs in relation to operating costs should be the ratio to take into consideration. However, if the main objective is related to substantial capital investment through installation of new plants and equipment or major expansion of existing plants the total input costs approach would be preferred.

High to medium initial investment requirements associated with energy conservation measures place a burden on the capital scarce economy. Lack of financing capabilities (particularly for small and medium sized units), as well as lack of incentives and investment programs impede the implementation of such measures. Furthermore, as far as more efficient and modern technology and equipment have to be imported from abroad outflows of foreign exchange place further pressure on the overall economy.

Additionally, more technology based barriers to energy efficiency improvements can be observed among others as follows (Karwa, 1998):

Process Conversion: Process conversion might not be possible due to constraints in plant layout or other technical reasons, or due to raw material limitation such as use of seasand or limestone with high moisture as raw materials. The units using this material, however, can be converted to semi-dry processes that utilize much less energy than wet processes.

Cogeneration: In the past, cogeneration systems were not adopted due to infrastructural constraints, non-availability of indigenous technology and low cost of other energy sources. Although the technological barrier has been nearly eliminated, high initial investment costs still prevent companies from the installation of cogeneration units and/or power generation through recovery of waste heat.

Technology and Equipment: Barriers to adoption of roller mills instead of ball or rod mills could be a high quartz content (more than 3%) of raw materials. High quartz content leads to increased abrasion of the working surfaces and reduces the lifetime of the mill. The advantage of roller mills being suited for uptaking waste heat to combine raw material drying with the grinding process is lessened by the fact that only long-dry process kilns would produce enough waste heat to dry raw materials with moisture content of more than 7%. For higher moisture content additional thermal energy would be needed.

4.3 Scenarios of Future Energy Efficiency

Three scenarios for future energy intensity have been developed linking the engineering and the economic analysis.

Engineering

<u>Scenario 1 (Frozen Efficiency)</u>

The frozen efficiency scenario (FE) assumes no further improvements in energy intensity as of 1993, the last year of the economic analysis. Using values for specific energy consumption for the industry and using future cement production based on demand projections (Section 2.3) and the assumption that demand will be fully met domestically, we calculate energy use for the year 2001, 2006 as well as 2011.

<u>Scenario 2 (Best Practice)</u>

The second scenario (Best Practice) assumes the adoption of world best (best practice) technology in India by a) the year 2001, b) the year 2006 and c) 2011. Using specific energy consumption values for world best technology as of today (Table 4.4) and assumptions on future cement production as explained above, we calculate energy consumption for the industry in the year 2001, 2006 and 2011 respectively under this scenario.

Economics

In contrast to the first two more engineering (bottom up) scenarios the next scenario (top down) assumes an economic point of view. According to economic theory energy price elasticities indicate a change in energy consumption due to a change in energy prices, all other input factors and prices remaining unchanged. With output being held constant, the elasticities simultaneously provide information on energy intensity. We can conclude the percentage change in energy intensity that would arise due to a percentage change in relative energy prices. This allows us to analyze changes in energy intensity under different energy price policy scenarios and time horizons.

<u>Scenario 3 (Best Practice Energy Price)</u>

The third scenario (Best Practice Energy Price (BPEP)) assumes that by the year 2001 (2006 and 2011 respectively) energy consumption will be reduced to today's best practice energy consumption, as presented in Table 4.4, by means of energy price policies alone. The exercise shows how high a energy price change relative to other factor prices would need to be to achieve this goal if no other incentives are used.

Results

Table 4.5 as well as Figure 4.1 present the results of the scenario analysis. The frozen efficiency (FE) case reveals that total final energy consumption in the cement sector will reach 422 PJ by the year 2001, 585 PJ by 2006 and 802 PJ by the year 2011 in case no efficiency improvement occurs at all. This presents a more than 3 fold increase compared to the 1993 base year. Due to the assumption of no further improvements in energy intensity and no structural change this change is solely driven by increases in cement production.

The Best Practice scenario shows that energy consumption could be reduced by 34% (31% and 29% respectively) compared to the frozen efficiency (FE) case if world best technology as of today would be adopted by the year 2001 (2006 and 2011 respectively). The analysis further reveals that by adopting today's best practice technology in 2001 improvements in energy efficiency would almost offset increases in the activity level. Despite enhanced cement production of 82% by 2001 a net increase in energy consumption of only 21% would be attained in adopting best practice technology. In the longer run (2006) increases in production activity (2.5 fold compared to 1993) together with efficiency improvement and structural change lead to a total final energy consumption of 403 PJ, a 74% increase compared to the 1993 base level. In 2011, best practice total final energy consumption would account for 566 PJ, a 2.4 fold increase in energy consumption over 1993 compared to a 3.5 fold increase in production activity.

Table 4.5: Scenarios for Energy Consumption in 2001, 2006 and 2011

Scenarios			Engineering		Economics
			Scenario 1	Scenario 2	Scenario 3
Scenario for 2001		1993 Base	FE	Best Practice*	BPEP (6.7%)
Electricity	GJ/t	0.42	0.42	0.33	na
Fuel	GJ/t	3.58	3.58	2.33	na
Specific Final Energy Consumption	GJ/t	4.00	4.00	2.65	2.66
Cement Production	Mt	57.96	105.61	105.61	105.61
Total Final Energy Consumption	PJ	231.8	422.4	280.3	280.9
Scenario for 2006		1993 Base	FE	Best Practice	BPEP (4.0%)
Electricity	GJ/t	0.42	0.42	0.33	na
Fuel	GJ/t	3.58	3.58	2.42	na
Specific Final Energy Consumption	GJ/t	4.00	4.00	2.76	2.74
Cement Production	Mt	57.96	146.31	146.31	146.31
Total Final Energy Consumption	PJ	231.8	585.2	403.2	401.5
Scenario for 2011		1993 Base	FE	Best Practice	BPEP (2.8%)
Electricity	GJ/t	0.42	0.42	0.34	na
Fuel	GJ/t	3.58	3.58	2.49	na
Specific Final Energy Consumption	GJ/t	4.00	4.00	2.83	2.84
Cement Production	Mt	57.96	200.47	200.47	200.47
Total Final Energy Consumption	PJ	231.8	801.9	566.4	569.1

na – not applicable

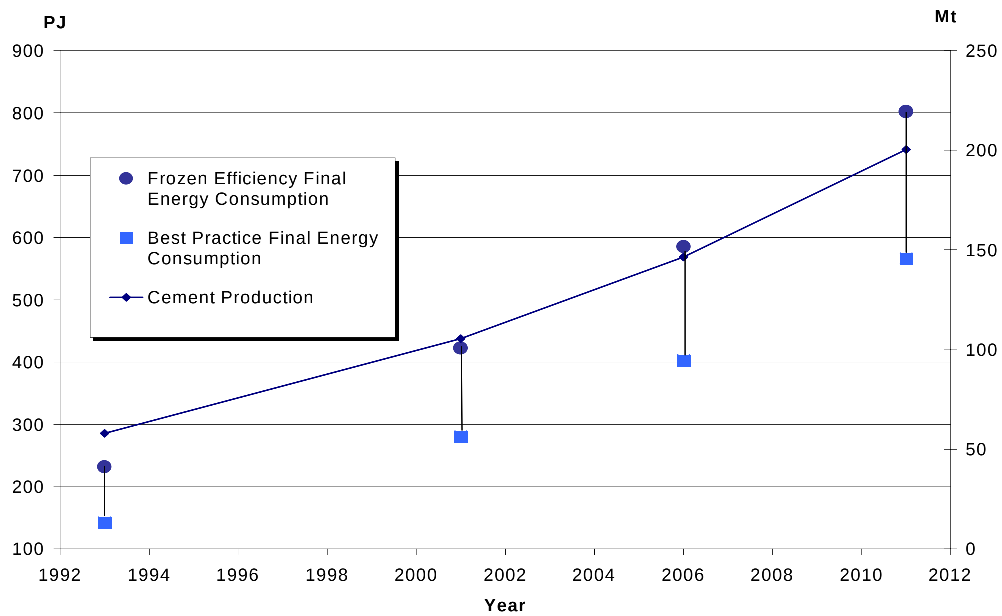
*Best practice calculations are based on the availability of fly ash and blast furnace slag for cement blending. Fly ash availability has been calculated from future coal consumption for thermal power generation which is assumed to grow at 3.3% between 1990 and 2000 and 2.1% between 2000 and 2010. Blast furnace slag is dependent on the availability of pig iron which is assumed to be about 85% of crude steel production. Forecasts for crude steel production are presented in Schumacher and Sathaye, 1998. Based on this, best practice clinker/cement ratios would be 68% in 1993, 74% in 2001, 78% in 2006 and 80% in 2011.

The economic analysis focuses on price policies to achieve reduction targets. It considers the effects of changes in energy price relative to other input prices on energy intensity. Such a change could be induced through the removal of subsidies on energy, through resources scarcity (especially of oil in the Indian case), or through environmental taxes or regulations.

The best practice energy price (BPEP) scenario shows that, keeping all other economic variables constant, an average annual nominal energy price increase of 6.7%, measured as increase in the fuel price index relative to other input prices, would be sufficient to result at total energy consumption equivalent to the best practice scenario by the year 2001.

Evaluation of the longer time horizon 2006 (2011 respectively) reveals that a lower relative energy price increase of 4.0% p.a. (2.8% p.a. respectively) would be needed for achieving best practice energy consumption by means of energy price policies alone. Consequently, the BPEP scenario proves that, considering the nature of technological change in India's cement industry as well as patterns of productivity change and input substitution, energy price incentives will lead to reduced energy consumption as would be achieved by adopting best practice technology.

Figure 4.1: Frozen Efficiency vs. Best Practice in Indian Cement Industry



Several comments should be acknowledged regarding the scenario analysis. Firstly, the assumption of adoption of best practice technology by the year 2001, 2006, or 2011 is ad hoc and not based on detailed assessments of specific technical and financial capabilities in India. Secondly, as mentioned above, improvements in electricity generation and distribution could further substantially contribute to energy efficiency improvement in the cement sector. Such improvement, however, has not been taken into account.

Thirdly, as within our economic modeling framework the economic scenarios provide ceteris paribus analyses of effects of relative energy price changes on energy intensity in an individual sector they do not take into account effects on other factors such as on energy supply, electricity generation, interfuel substitution etc. Furthermore, increases in energy prices will be accompanied by increases in other factor prices that will in turn have different impacts within the economic modeling framework. The scenario analysis can be understood as a sensitivity analysis indicating that energy price policies are effective in reducing energy intensity.

4.4 Effects on Carbon Dioxide Emissions

In a last step we will calculate carbon dioxide emissions and mitigation potentials through the adoption of energy efficiency measures and structural change. In cement production carbon dioxide emissions arise from fossil fuel use and from non-fuel related sources (decarbonization of limestone). Structural change is therefore beneficial not only in reducing energy related carbon dioxide emissions but additionally in reducing limestone consumption and its inherent carbon release. Energy efficiency improvement is effective in saving scarce resources and input costs, as well as in reducing carbon emissions and thus mitigating global climate change.

Table 4.6: Carbon Dioxide Emissions: India vs. Best Practice*

		1991	1992	1993
India:				
	tCO_2/t cement	0.86	0.91	0.89
Total Emissions	Mt CO_2	45.97	49.20	51.54
- Emissions from Calcination	Mt CO_2	22.51	22.46	25.39
- Emissions from Fuels	Mt CO_2	23.46	26.74	26.15
Best Practice:				
	tCO_2/t cement	0.63	0.63	0.63
Total Emissions	Mt CO_2	33.83	34.15	36.55
- Emissions from Calcination	Mt CO_2	18.18	18.34	19.63
- Emissions from Fuels	Mt CO_2	15.65	15.81	16.92
Total Savings Potential	%	26.4%	30.6%	29.1%

*Calculated based on best practice energy consumption as presented above. The optimal output mix and thus clinker-cement ratio for 1991 and 1992 is assumed to be the same as for 1993 (see Appendix G). Carbon intensity factors by fuels used are presented in Appendix H. Non-fuel emissions from calcination are assumed at 136 kg C/t of clinker (Worrell et al., 1995).

Carbon dioxide emissions from different fuels have been calculated as presented in Table 4.6. For India, they are based on total energy consumed in the cement sector differentiated by fuel type (see Section 2.3.2). Best practice emissions calculations are based on best practice energy consumption as presented in Chapter 4.2.1, assuming the same fuel shares as in 1991-1993 (94% coal and 6% petroleum products for thermal energy production). Given the priority allocation of natural gas to fertilizer production, no conversion to natural gas has been assumed for best practice cement production. Carbon emissions per unit of fuel used as well as the carbon intensity per unit of energy for the different fuels specific to India are presented in Appendix H. Non-fuel emissions from calcination are assumed at 136 kg C/t of clinker. Complete conversion of carbon to CO_2 has been assumed.

The table shows that carbon dioxide emissions amounted to about 0.86 tonne of CO_2 per tonne of cement in 1993. In 1994, emissions were higher at 0.91 t CO_2 per tonne of cement and slightly lower again in 1995 at 0.89 t CO_2 per tonne of cement. Total emissions in 1993 equal 51.54 Mt CO_2, 25.39 Mt from the calcining process and 26.15 Mt from fossil fuel combustion. The best practice case reveals a reduction potential for CO_2

emissions of 27% to 30% for the three years under consideration. Best practice CO_2 emissions amount to only 0.63 tonnes of CO_2 per tonne of cement. While currently in India CO_2 emissions from fossil fuel combustion exceed emissions caused by calcination, this would be reversed if best practice were assumed. In 1993, best practice would reduce total emissions to 36.55 Mt CO_2, 19.63 Mt originating from calcination and 16.92 Mt from fossil fuel use.

The scenario forecast (Table 4.7) reveals that best practice technology and structure would lead to substantial reductions in CO_2 emissions. While in the frozen efficiency scenario emissions in 2011 will be 3.4 fold the 1993 base year emissions, best practice emissions will surmount 1993 base year emissions only 2.8 fold. In 2001, emissions from frozen efficiency will exceed 1993 base year emissions at 80%. Best practice, however, will only lead to 40% increase in emissions. As with energy efficiency improvement, abatement potentials are declining over time due to constraints in the availability of fly-ash and blast furnace slag for cement blending. The optimal output mix, as given in Appendix G, shows that because of unutilized assets of additives, such as fly-ash and blast furnace slag, the optimal share of PSC and PPC would be much higher in the short run. With growing cement production, however, these inputs will become increasingly scarce, pushing back the shares of PPC and PSC in total cement production.

Table 4.7: Total Carbon Dioxide Emissions

	Base Case	Frozen Efficiency (FE)			Best Practice		
	1993	2001	2006	2011	2001	2006	2011
tCO_2/ t	0.89	0.88	0.88	0.88	0.68	0.71	0.73
Cement (Mt)	57.96	105.61	146.31	200.47	105.61	146.31	200.47
Total CO_2 (Mt)	51.54	92.63	128.32	175.83	72.02	103.71	145.73

Note: Output structure as of 1997 (85% clinker-cement ratio, Output Mix: OPC 71%, PPC 18%, PSC 10%) has been used for frozen efficiency calculations. Specific energy consumption is frozen at 1993 levels. Optimal clinker-cement ratio and output mix underlying best practice analysis have been calculated on the basis of predicted availability of fly-ash and blast furnace slag, as presented in Appendix G.

Yet, as presented above, the best practice scenario will result in emissions about 17-22% lower than the frozen efficiency scenario. Since no conversion towards natural gas has been assumed additional savings could be gained by fuel switching. Our findings strongly support that energy conservation measures as well as structural changes are highly effective in reducing carbon emissions.

5. Summary and Conclusions

In this paper, we investigated India's cement sector from various perspectives. We developed economic as well as engineering indicators for productivity growth, technical change and energy consumption that allowed us to investigate savings potentials in specific energy use as well as carbon dioxide emissions. We discussed our findings within a broader context of structural and policy changes in the sector. The economic analysis showed that productivity has slightly increased over time. The increase was mainly driven by a period of progress between 1983 and 1993 following partial decontrol of the cement sector in 1982. Before 1983 productivity declined probably due to government protection regarding prices and distribution, inefficiencies in plant operation and constraints in essential input factors. Since 1991, the sector has suffered a tremendous downfall in accordance with overall economic recession.

We further pointed out cost effective low cost potentials for reducing energy consumption as well as carbon emissions. In comparing Indian energy consumption to best practice energy consumption we showed that energy savings of up to 38% could be achieved. However, the implementation of initiatives towards energy efficiency is being hampered by barriers both of general and process specific nature occurring at the macro and micro level of the economy.

The analysis reveals that energy policies in general and price-based policies in particular are efficacious for overcoming these barriers in giving proper incentives and correcting for distorted prices. Through the removal of subsidies, energy prices would come to reflect their true costs, while environmental taxes could be imposed to internalize the external costs (including environmental costs) of energy consumption. In the short term, energy price increases would push less productive and inefficient mostly smaller units out of the market resulting in overall sectoral efficiency and productivity improvement. In order to improve energy use and thus reduce carbon emissions on a long term basis, substantial further investments in energy efficiency technologies for existing and new plants have to be made. Therefore, sectoral policies should be devoted to the promotion of such investments. Since our economic results suggest that price-based policies although effective in reducing energy use and carbon emissions could have a negative long run effect on productivity, and thus welfare, an optimal policy strategy would consist of a mix of regulatory and price based incentives within a set political and economic framework.

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Appendix

Appendix A

Production, Capacity and Capacity Utilization in Indian Cement Plants

Year	Production (Mt)			Installed Capacity (Mt)			Capacity Utilization (%)		
	Total	Large Plants	Small Plants	Total	Large Plants	Small Plants	Total	Large Plants	Small Plants
1970-71	13.9			17.4			79.9		
1975-76	16.3			20.6			79.1		
1978-79	19.6			21.6			90.7		
1980-81	18.66	18.55	0.11	26.99	26.86	0.13	69.1	69.1	84.6
1981-82	21.0	20.91	0.1	29.35	29.22	0.13	71.6	71.6	76.9
1982-83	23.3	23.18	0.12	33.51	32.98	0.53	69.5	70.3	22.6
1983-84	27.0	26.74	0.26	36	35.22	0.78	75.0	75.9	33.3
1984-85	30.1	29.56	0.57	42	40.69	1.31	71.7	72.6	43.5
1985-86	33.1	32.05	1.08	44	42.35	1.65	75.3	75.7	65.5
1986-87	36.4	34.83	1.57	54.4	52.31	2.09	66.9	66.6	75.1
1987-88	39.4	37.41	1.96	57.47	54.51	2.96	68.5	68.6	66.2
1988-89	44.1	41.75	2.33	58.97	55.04	3.93	74.7	75.9	59.3
1989-90	45.4	42.91	2.5	61.55	56.96	4.59	73.8	75.3	54.5
1990-91	48.9	45.75	3.15	64.36	59.12	5.24	76.0	77.4	60.1
1991-92	53.6	50.61	3	66.56	61.31	5.25	80.5	82.5	57.1
1992-93	54.1	50.72	3.36	70.19	64.94	5.25	77.0	78.1	64.0
1993-94	58.0	54.09	3.87	76.88	71.18	5.7	75.4	76.0	67.9
1994-95	62.4	58.35	4	83.69	77.99	5.7	74.5	74.8	70.2
1995-96	69.6	64.45	5.1	97.23	88.23	9	71.5	73.0	56.7
1996-97	76.2	69.98	6.24	105.2			72.4		

Source: Karwa (1998); data for 1975 and 1978 from Chakravarty (1989).

Appendix B

Gross Value Added in the Construction Sector

(constant 1980/81 Factor Costs)

Year	GVA Construction (billion Rs.)	Growth (relative annual)
1977	58.3	
1978	57	-2.2%
1979	54	-5.3%
1980	61.1	13.1%
1981	64.5	5.6%
1982	61.5	-4.7%
1983	65.8	7.0%
1984	68.3	3.8%
1985	71.8	5.1%
1986	75.4	5.0%
1987	77.8	3.2%
1988	83.8	7.7%
1989	88.1	5.1%
1990	98.3	11.6%
1991	100.5	2.2%
1992	103.9	3.4%
1993	105.2	1.3%
1994	112.4	6.8%
1995	118.4	5.3%
Source: ADB (1995,1997)		

Appendix C

Cement Historical Estimates

Author	Method/Measure	Source of Data	Period	Growth Rate
Ahluwalia (1991)	TFPG : TL	ASI	1960-85	-0.5
	PP: Capital			-1.4
	PP: Labor			1.3
	Cap/Lab Ratio			2.7
Arora (1987)	TFPG: TL	ASI	1973-81	-1.96
	PP: Capital			-1.66
	PP: Labor			2.29
	Cap/Lab Ratio			5.19
Arya (1981)	TFPG: Solow	CMI/ASI	1951-70	0.25
	PP: Capital			-6.00
	PP: Labor			2.60
	Cap/Lab Ratio			9.15
	TFPG: Solow		1951-56	-3.04
	TFPG: Solow		1956-70	2.08
	CD Prod. Function	Company Reports	1956-72	0.8-6.8
CSO (1981)	TFPG: Kendrick		1960-77	1.62
	PP: Capital			1.86
	PP: Labor			1.12
	Cap/Lab Ratio			-0.74
	TFPG: Kendrick		1960-71	-0.30
	PP: Capital			-1.44
	PP: Labor			2.37
	Cap/Lab Ratio			3.81
	TFPG: Kendrick		1969-77	2.99
	PP: Capital			4.54
	PP: Labor			-0.51
	Cap/Lab Ratio			-5.05
Goldar (1986)	TFPG: Kendrick	ASI	1960-70	0.50
	PP: Capital			-0.37
	PP: Labor			2.66
	Cap/Lab Ratio			3.05
Gupta (1973)	TFPG: Kendrick	CMI/ASI	1946-65	-1.06*
	PP: Capital			-0.55
	PP: Labor			2.51
	PP: Materials			-1.26
	Cap/Lab Ratio			3.06
	TFPG: Kendrick		1946-58	-0.86*
	PP: Capital			-2.8
	PP: Labor			2.68
	PP: Materials			-0.31
	TFPG: Kendrick		1958-65	2.65*
	PP: Capital			8.72
	PP: Labor			1.74
	PP: Materials			-1.02
Mahopatra (1970)	TFPG: Solow	CMI/ASI	1949-64	1.8*

Cement Historical Estimates (contd.)

Author	Method/Measure	Source of Data	Period	Growth Rate
Mehta (1980)	TFPG: Solow TFPG: Kendrick PP: Capital PP: Labor Cap/Lab Ratio CD Prod. Function	CMI/ASI	1953-64	-5.4 -5.5 -5.6 -1.6 4.0 6.1
Pradhan (1998)	TFPG: TL TFPG: TL TFPG: TL TFPG: TL		1963-92 1963-71 1972-81 1982-92	1.71* -5.51* 0.01* -6.79*
Sawhney (1967)	TFPG: Kendrick PP: Capital PP: Labor PP: Materials Cap/Lab Ratio	CMI/ASI	1950-63	1.9 1.5 7.3 1.2 5.8
Sinha (1970)	TFPG: Kendrick PP: Capital PP: Labor Cap/Lab Ratio		1950-63	1.70 1.91 4.70 2.79
Source: Mongia and Sathaye (1998a)				

Notes: Growth rates are per cent per annum, either compound annual growth rates, semi-log trend rates or simple average growth rates. * indicates total productivity measures.

Appendix D

Using data from 1980/81 to 1995/96 (1993/94 for $GDP_{construction}$), the following simple regression relationships between cement production and a) GDP_{total}, b) $GDP_{industry}$ and c) $GDP_{construction}$ have been obtained:

a) $C = 3.25E\text{-}04 * GDP_{total} - 19.11$ $\qquad R^2 = 0.986$

(31.74) (-9.71)

b) $C = 1.02E\text{-}03 * GDP_{industry} - 9.58$ $\qquad R^2 = 0.984$

(29.62) (-5.33)

c) $C = 0.789811 * GDP_{construction} - 25.42$ $\qquad R^2 = 0.973$

(22.53) (-8.35)

where C indicates cement production. Cement is measured in Mt while GDP_{total}, $GDP_{industry}$ and $GDP_{construction}$ are measured in 1980-81 const. Rs. (Government of India, Economic Survey, 1997 and ADB, 1995, 1997). T-statistics are given in parenthesis. All estimates are statistically significant.

Appendix E

Assumed Compositions of Cement Types, derived from European Standard ENV 197-1 (1992)

Cement Type	Clinker (%)	Filler[1] (%)	BF-slag (%)	Fly-Ash (%)	Pozzolanes (%)
Type I Ordinary Portland	95%	5%	-	-	-
Type II Portland Composite	65%	5%	←	30%	→
Type III Portland Slag	30%	5%	65%	-	-
Source: Worrell et al. (1995).					

[1] Mainly gypsum and anhydrite are used as filler.

Appendix F

Energy Conservation Options, Investment Requirements and Possible Savings

Energy Conservation Options	Investment Requirements	Possible Savings
Energy Efficient Technology and Equipment		
Gyratory crushers, mobile crushers and single stage crushers vertical roller mills		Upto 30% on electrical energy 15-30% compared to power consumption of ball mill
Roller press		4-8 kWh/t of cement in pregrinding system
High efficiency separators		Upto 30% on electrical energy
Variable speed AC drives		Upto 30% on power consumption of the drive
Solid state motor controllers and soft starters	Rs. 1.5 lakhs	Upto 2% on power consumption of the drive
Energy efficient motor	Upto Rs. 3 lakhs	Upto 5% on power consumption of the drive
Mechanical conveying systems over pneumatic conveying systems for dry raw meal and cement	Rs. 0.4-1.25 lakhs	Upto 5% on power consumption of the drive
High efficiency fans	Rs. 30-50 lakhs	10-30% on power consumption of the drive
Improved multi-channel burners		About 2% on heat consumption
5/6 – stage preheaters		30-40 kcal/kg clinker

Energy Conservation Options, Investment Requirements and Possible Savings **(contd.)**

Energy Conservation Options	Investment Requirements	Possible Savings
Input Substitution and Output Modification		
Manufacture of blended cements like PPC, PSC	Nil	Heat energy in kcal/kg cement: 20% in case of PPC and 45% in case of PSC; Electrical Energy: PPC 10-15%, PSC 20-30%
Waste heat utilization	About Rs. 2.5 crore per MW	About 4.5 MW for 3000 tpd plant
Coal substitution by lignites		Fuel substitution to counter shortage of coal and utilization of waste
Process Specific Measures		
Conversion from wet to dry process	Rs. 1250-2700 per tonne of annual capacity	Around 700-800 kcal/kg clinker installed
Proper preblending of raw materials to give optimum raw mix design	Nil	
Proper control over coal mix being fed into the kiln/precalcinator	Nil	
Proper control over process parameters for optimum and efficient operation	Nil	
Use of grinding aids, mineralizer and slurry thinners	Nil	
Organizational Measures		
Proper maintenance, monitoring and preventive maintenance to minimize downtime of machinery and plant	Negligible	Depends on the extent of equipment availability and on stream days of the plants
Prevention of false air entry in the circuit by sealing the air holes in the kiln	Negligible	Upto 10% on thermal energy and upto 2% on electrical energy depending on extent of false air
Regular inspection and maintenance of capacitor banks and installing additional banks, if required	Rs.200-300/KAVR	Dependent on extent of power factor improvement
Regular inspection of interlocking arrangement to prevent idle running of motors and machinery	Negligible	
Effective load management	Negligible	Upto about 15% in maximum demand
Regular inspection of motors for identifying underloading, and reshuffling of the same	Negligible for re-shuffling, dependent on size of motor for replacement	Depends on extent of underloading and size of motor
Source: Karwa (1998).		

Appendix G

Optimal Output Mix and Clinker/Cement Ratio

	OPC	PPC	PSC	C/C Ratio
1993	25.4%	61.1%	13.5%	68%
2001	44.9%	43.5%	11.7%	74%
2006	54.7%	34.8%	10.5%	78%
2011	61.8%	28.2%	10.0%	80%

Appendix H

Heating Values and Carbon Intensity of Fuels in Cement Manufacturing

Fuel	Units	Heating Value (GJ/unit)	Carbon emissions (t/unit)	CO_2 Intensity (tCO_2/GJ)
Coal	tonne	17.59	0.43	0.090
Petroleum Products	tonne	41.87	0.85	0.074
Electricity*	1000 kWh	3.6	0.31	0.316
Source: Das and Kandpal (1997a); Das, Mehra et al. (1993); .Mehra and Damodaran, (1993).				

*Assuming a conversion efficiency of 24.8% in a coal fired thermal power plant, equivalent to the use of 0.72 kg coal/kWh.