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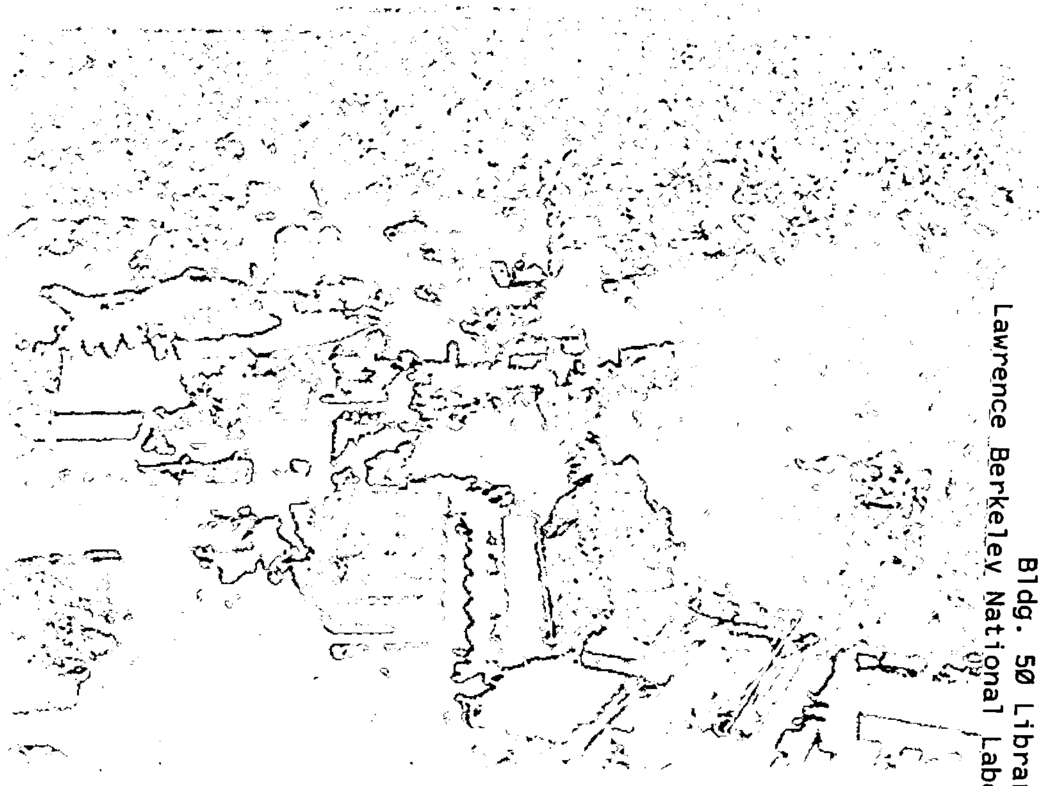

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India's Aluminum Industry: Productivity, Energy Efficiency and Carbon Emissions

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Abstract

Historical estimates of productivity growth in India's aluminum 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 decreased slightly by 0.2% as indicated by the Translog index. Calculations of the Kendrick and Solow index support this finding. Using a translog specification the econometric analysis reveals that technical progress in India's aluminum sector has been biased towards the use of energy, while it has been labor saving. The decrease was mainly driven by a decline in the 1970s when capacity utilization was low and the energy crisis hit India and the world. From the early 1980s on productivity recuperated. The commissioning of an additional aluminum plant in 1987 and subsequent industry liberalization affected total productivity growth positively. Since 1991, however, the sector suffers a downfall in accordance with overall economic recession. We examine the current changes in structure and energy efficiency undergoing in the sector. Our analysis shows that the Indian aluminum sector has high potential to move towards world-best technology, which will result in fewer carbon emissions and more efficient energy use. Substantial energy savings and carbon reduction options exist.

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1. Introduction

The aluminum sector presents 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 most 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 aluminum 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. We introduce the aluminum industry in more detail taking into account industry specific aspects such as structural composition, production, technologies, energy consumption within processes, sector specific policies etc. This following we derive both statistical and econometric estimates of productivity growth for the aluminum sector over time. For the statistical analysis we develop the Kendrick and Solow indices while for the econometric analysis a translog cost function approach using both cross-state and national time series data is employed. 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 emission 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 aluminum industry structure. It compares world best technologies to Indian technologies and identify potentials and barriers to the adoption of such efficiency improvements. We conclude the report in highlighting the energy efficiency and productivity improvements that could be achieved by employing more efficient technologies.

2. Aluminum Industry

2.1 The Aluminum Industry in Context

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 consume 38.8% of all fuels consumed in the manufacturing sector (Table 2.1)[1]. The aluminum sector holds a relatively small share in regards to output within these energy intensive industries. In 1993, it accounted for 5% of value of output within the six industries and for 0.5% in the manufacturing sector. However, its share in total fuels consumed in the manufacturing sector is substantially higher at 2.6%.

Table 2.1: Economic Indicators for the Aluminum Industry

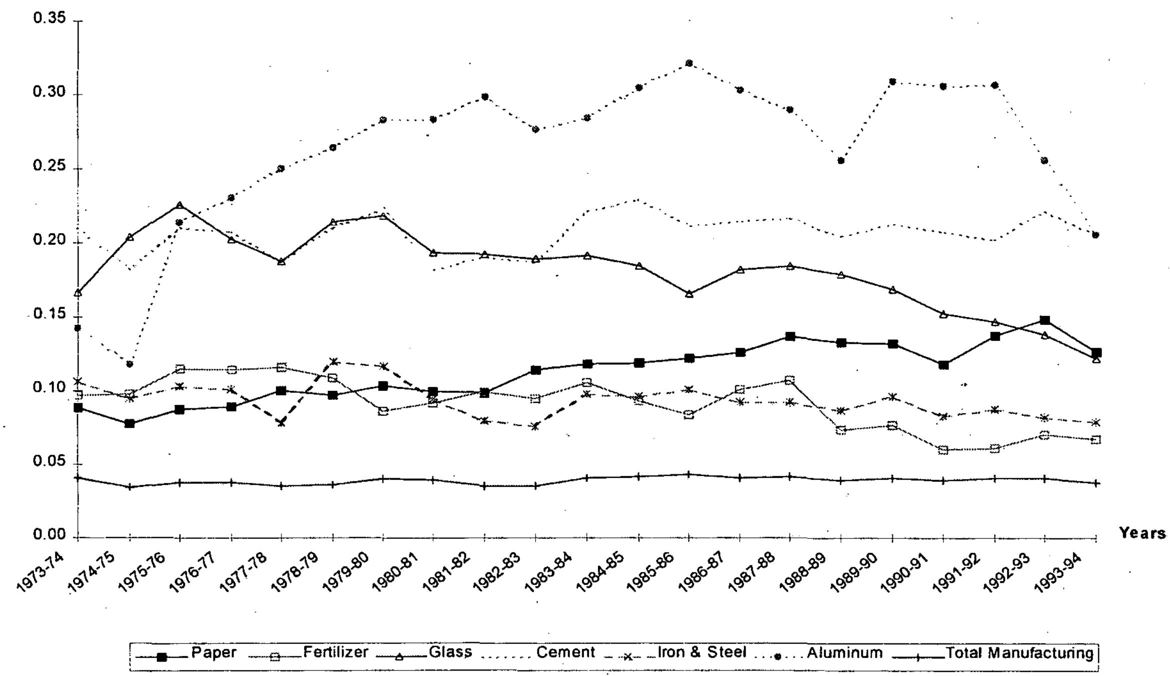
	Unit	Aluminum	Aggregate of Six Energy Intensive Industries	Aggregate Manufacturing
Growth in Value of Output[1]				
Nominal				
1973-1993	% p.a.	16.2	16.4	15.1
1973-1988	% p.a.	18.7	16.9	14.7
1988-1993	% p.a.	8.6	15.2	16.2
Real				
1973-1993	% p.a.	5.1	7.9	7.4
1973-1988	% p.a.	7.1	8.7	7.6
1988-1993	% p.a.	-0.9	5.6	6.7
In 1993-94:				
VO Share in Aggr. Manufacturing (nominal)	Sector VO/ Manuf. VO	0.9%	16.8%	100%
Sector Fuel Share in Aggr. Manuf. (nominal)	Sector Fuel/ Manuf. Fuel	2.6%	38.8%	100%
Share of Fuel Costs in Value of Output (nominal)	Sector Fuel/ Sector VO	19.3%	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 aluminum sector has been increasing over the last 20 years. As seen in Table 2.1 major increases in real VO (7.1%) took place between 1973 and 1988, while growth was declining thereafter (1988-93) at -0.9%. Compared to the aggregate of the six energy intensive industries growth in the aluminum sector was slightly lower than the average of the six energy intensive industries between 1973 and 1988 and fell significantly short of the average between 1988 and 1993. The significant shortfall in the second subperiod, however, is exclusively driven by a drop in production in 1992. Between 1988 and 1992 value of output in the aluminum sector grew at considerable 5.6%. The ups and downs led to an overall positive growth in output between 1973 and 1993 of 5.1% which is well below the average of 7.9% of the energy intensive industries.

[1] Value of output is defined as the gross value of production; fuels consumed represent the total purchase value of fuels, lubricants, electricity, etc. consumed by the factory. Detailed definitions are given in the Annual Survey of Industries (Government of India, ASI, various years).

Figure 2.1: Changes in Energy Intensity of Various Industries
(Real Fuel Cons. (1973-74 const. Rupees)/Real Value of Output (1973-74 const. Rupees))



In 1993-94, the aluminum sector accounts for 4.2% of total fuels consumed in the manufacturing sector. Within the group of energy intensive industries, the share of fuels consumed per unit of output (VO) is higher than average with 19.3%. Compared to the average manufacturing fuel consumption per unit of output at 6.8% the aluminum sector consumes three times the amount of fuels per unit of output (VO). Figure 2.1 displays the energy intensity of the aluminum sector in real values. The 'real-value' indicator reflects the changes in physical energy intensity over time and gives a comparison to other sectors. Aluminum production was most energy intensive almost over the whole time period. Only in the early years (up to 1975) it was surpassed by energy consumption per unit of output in the glass and cement sector.

2.2 Aluminum Process

Aluminum can be produced through primary or secondary processing. In the primary industry aluminum industry the main process steps include 1) bauxite mining, 2) production of alumina, 3) production of aluminum, and 4) fabrication aluminum products through casting, rolling and extrusion. In the secondary process aluminum is produced by remelting aluminum scrap. (Phylipsen et al., 1998)

In the primary process, bauxite, after mining, is converted to alumina. Most of the world's alumina production is based on the Bayer process. Bauxite (aluminum containing ore) is converted alumina by treating it with sodium hydroxide at high temperature and pressure. The Bayer process is advantageous because of its capability to handle bauxite of various ranges and because of its flexibility to produce a wide variety of alumina. The production of alumina can take place at the bauxite mining site, at the aluminum production site or anywhere else.

Alumina is then electrolytically reduced to primary aluminum using the worldwide adopted Hall-Heroult process. To feed the electrolysis cells (smelter) a conversion from high voltage AC to low-voltage DC is required. Carbon anodes, either in form of pre-baked anodes which are produced in a separate process and require less electricity in the smelter or Söderberg paste, are used for the reaction. About 70% of the world's aluminum production and 60.3% of total Indian capacity is based on pre-baked anodes (Das and Kandpal, 1998). The electrodes of the electrolysis can be partly recycled and used as feedstock for further anode production. The crude, hot aluminum can be cast into intermediate products (e.g. ingots), and processed into final products.

Secondary aluminum production is much less energy intensive. It involves a scrap processing step and subsequent remelting before it can be further produced. Usually, secondary aluminum is of lower quality than primary aluminum, and used for different products. (Phylipsen et al. 1998)

2.3 Aluminum Production in India

Aluminum production in India is highly concentrated with only five companies accounting for the entire production capacity of 682,000 tonnes[2] in 1996-97. With production of 0.53 million tonnes (Mt) India holds a share of less than 3% in world aluminum production (Roy et al., 1998; CMIE, 1996). The two most recently established plants, BALCO and NALCO, are public entities, while the remaining three are in the private sector (Nayar, 1990). Aluminum has been in short supply for most of the past. However, with the commissioning of NALCO in 1987 production capacity increased substantially. India achieved self sufficiency in aluminum production in 1991. At the same time export started. (Roy et al., 1998; CMIE, 1996; Nayar, 1990)

Table 2.2: Annual Primary Aluminum Capacity and Production **('000 tonnes)**

	Installed Capacity	Production	Capacity Utilization
1975-76	246	187	76%
1980-81	331	199	60%
1985-86	362	260	72%
1990-91	580	451	78%
1991-92	625	512	82%
1992-93	625	486	78%
1993-94	625	465	74%
1994-95	625	478	77%
1996-97	682	523	77%

Source: TERI (1996).

Aluminum capacity, production and capacity utilization over time is presented in Table 2.2. In addition, Table 2.3 gives more detailed information on the five plants, the year of

[2] metric tonnes, abbreviated as t (million tonnes as Mt) in the following.

commissioning, their production capacity, actual production and capacity utilization for the year 1996-97. Installed capacity increased with expansion efforts at existing sites. No new plant was commissioned between 1975 and 1987. National Aluminium (NALCO), the plant set up most recently, is the largest plant with an installed capacity of 230,000 tonnes. It accounted for almost 40% of total production in 1996-97. Average capacity utilization was low around 60% in the first half of the 1980s and well above 70% thereafter (Table 2.2). In 1996-97, it was at an average of 77%, ranging widely from 34% at Indian Aluminium Co. (INDAL) to 92% at Bharat Aluminium (BALCO).

Table 2.3: Profile of Aluminum Companies (1996-97) **(tonnes per year)**

Company	Year of Commissioning	Capacity	Production	Capacity Utilization
BALCO	1975	100,000	91,540	92%
HINDALCO	1962	210,000	166,272	79%
INDAL	1943-54*	117,000	39,840	34%
NALCO	1987	230,000	203,823	89%
MALCO	1964	25,000	21,525	86%
TOTAL		**682,000**	**523,000**	**77%**
Source: Das and Kandpal (1998), Roy et al. (1998).				

*plants at different locations were commissioned at different points of time

All plants are based on foreign technology. While most plants have rather old technology, NALCO has the most energy efficient state of the art technology from France. With its high foreign exchange liability NALCO is the only export oriented plant. Fixed costs at NALCO are highest with 60% as compared to 35% at HINDALCO and 40% at BALCO. Madras Aluminium (MALCO) went out of production in 1991. In 1994, however, it resumed production with a change in management (Roy et al., 1998).

Demand for aluminum products has been increasing at 3.8% p.a. in the 1980s. The growth rate is rather low compared to the average growth rate of 6% for all industries. Aluminum based products, such as automobiles, buildings, packaging including beverage cans and other containers are only emerging as demand segments in India (Radhakrishnan, 1987). Furthermore, aluminum is in competition with its substitutes, such as glass, plastic, steel etc.

Table 2.4: End Use of Aluminum: India and World (%)

Sector	India	World
Electrical	35	8
Transport	18	28
Construction	8	19
Packaging	7	20
Consumer Durables	12	5
Others	21	20
Total	100	100
Source: Roy et al. (1998).		

In addition, government control in the aluminum sector had a strong influence on the production and consumption mix. While during the period of regulation, 50% of aluminum had to be produced as electric grade aluminum for use in the electrical sector, after decontrol of this distribution requirement the share of aluminum used by the electrical sector has decreased to 35%. An increasing share is now consumed in the transport and packaging sector. Comparing end use mix in India to the world, as shown in Table 2.4, reveals a still dominating share of the electrical sector at the expense of almost all other segments.

2.3.1 Raw Materials

The main raw material used for aluminum production is bauxite. Bauxite reserves are abundant in India which possesses an estimated 8% of the world's known reserves (Das and Kandpal, 1998; Lal, 1985). The amount and share of bauxite consumed in relation to other raw materials such as caustic soda, calcined petroleum coke, coal tar pitch and aluminum fluoride depends on the quality of bauxite (Al_2O_3 content) and the technology used and varies across producers. NALCO and INDAL have captive bauxite mines which ensure stable quality and continuos supply for production. Other plants, such as HINDALCO and BALCO, receive their supply from multiple sources with differing quality (Roy et al., 1998). On average, 5.21 tonnes of bauxite are required to produce 1.93 tonnes of alumina which is needed on average to produce one tonne of hot metal (aluminum). An additional 20 kg of cryolite and 450 kg of graphite are required to produce one tonne of aluminum. (Roy et al., 1998; Das and Kandpal, 1998)

2.3.2 Energy Use

Aluminum production is highly energy intensive consuming high shares of both thermal and electrical energy. Table 2.5 shows energy consumption for the years 1980-1985 and for 1994-95. Average final energy consumption per tonne of aluminum is high at about 112 GJ/tonne of aluminum in the early 1980s. By 1994, it has declined to an average of 90.8 GJ/tonne of aluminum which is about two and a half times that of steel (35.5 GJ/tonne of crude steel). (Schumacher and Sathaye, 1998)

Table 2.5: Specific Energy Consumption (1980-95) **(GJ/tonne of hot metal)**

	1980-81	1981-82	1982-83	1983-84	1984-85	1994-95
Electrical Power	66.9	65.6	66.3	66.7	66.1	60.4
Thermal Energy	48.7	46.2	45.3	47.1	46.7	30.4
Final Energy	115.6	111.8	111.6	113.8	112.8	90.8
Source: 1980-85: Government of India (1988); 1994-95: Das and Kandpal (1998).						

Fuel consumption depends very much on the grade of bauxite and the technology adopted for digestion, while electrical power consumption depends more on the hardness of the ore. Larger size plants usually use less of both fuel and electricity. Energy consumption, as seen in Table 2.5, thus varies by plant and process step.

INDAL and the most recently built plant, NALCO, are the most efficient plants with specific final energy consumption of only 86.25 GJ/tonne and 87.09 GJ/tonne of aluminum (Das et al., 1998). Average electricity and thermal energy consumption in alumina production amounts to 400 kWh and 14.2 GJ per tonne of alumina. Alumina processing is based on coal and fuel oil, except for the calcination step where only fuel oil is utilized. Reducing alumina to aluminum by means of electrolysis is the most energy intensive step in aluminum production. Almost 100% of the total electricity and nearly 67% of total energy is consumed in the smelting process (electrolysis). Electricity consumption in the smelter depends on the kind of anodes used and ranges from 15 to 23 MWh. Pre-baked anodes reduce electricity consumption in the smelter. They are used by HINDALCO and NALCO (accounting for about 60.3% of total capacity). (Das and Kandpal, 1998)

All units except MALCO and INDAL's plant at Belgaum have captive power plants. The two public sector units, NALCO and BALCO, generate all necessary power on-site while HINDALCO and INDAL have capacities of 90% and 33% of their electricity requirement for on-site power production. Due to severe power problems in form of unsteady power supply from the national grid and frequent power outages at INDAL's Belgaum plant, the smelter plant had to be closed. MALCO, as well, has to rely on uncertain power supply from the state electricity board (Lal, 1985; Roy et al., 1998). Its electricity consumption is highest with 23 MWh for electrolysis. In the final step of aluminum fabrication another 3550-4700 kWh of electricity per tonne of product are consumed for rolling, extrusion, and drawing (Roy et al., 1998).

Table 2.6: Energy Consumption by Plant and Process (1994-95)

	Alumina (per tonne of alumina)				Smelter (per tonne of aluminum)		SEC (per tonne of hot metal)
	Steam (tonne)	Coal (tonne)	Fuel Oil (kg)	Electricity (kWh)	Thermal Energy (GJ)	Electricity (kWh)	Final Energy (GJ)
BALCO	3.34	0.59	121	470	1.26	18022	99.65
HINDALCO	4.24	0.98	75.6	362	2.51	15341	92.53
INDAL	2.4	-	220	250	0.84	17921	86.25
NALCO	3.2	0.7	84	413	4.19	15548	87.09
Source: Das and Kandpal (1998).							

Notes: Fuel Oil for BALCO includes consumption for steam generation; INDAL does not use coal for steam generation.

Secondary aluminum production requires only about 5 to 6% of the energy needed for primary aluminum production. Roy et al. (1998) estimate energy consumption of 8.4 GJ/tonne aluminum for secondary aluminum from clipping, 10.9 GJ/tonne aluminum for aluminum from dry boring and turning, and 18.1 GJ/tonne aluminum for secondary aluminum from high iron scrap.

2.4 Policy

The Indian aluminum industry had been under government regulation on pricing and distribution (Aluminum Control Order) since 1970. In the early stages control related only to the production of electrical grade metals. The distribution control of 1975 mandated manufacturers to produce 50% EC grade metal. The rationale behind this policy was to make aluminum available for the country's power sector which affected the extent to which aluminum could be used in transport, building, construction and packaging.

In 1978, the price control was extended to all types of aluminum, while the distribution control with regards to EC grade metal production continued. The retention prices were based on cost calculations plus a post standard tax return on share holders' funds but could not always keep pace with actual cost increases at a specific plant. In the late 1970s and early 1980s costs of production of aluminum at BALCO, for example, were higher than at other industries and the retention price could not cover these costs. Retention prices were revised regularly as production costs increased sharply particularly due to escalating costs for power generation. In years, where retention prices were not adjusted (1982 and 1983), all four aluminum producers suffered uncovered production costs.

Protection of the aluminum industry led Indian aluminum prices to diverge significantly from world market prices as fixed at the London Metal Exchange (LME). Between 1970 and 1978 the price ratio of Indian to world aluminum prices was about 1.65 (in 1975). This high ratio continued until the late 1980s with a peak in 1982. Only in 1988 the price of aluminum ingots in India was lower than the international price which reverted immediately thereafter again in 1989. Prices were administered by the government to protect the 'infant' industry in its early stages of development. It was thought to balance the interest of consumers and producers in India, ensuring availability of aluminum to the consumers at a fair price while at the same time ensuring steady and foreseeable returns to producers.

With the commissioning of NALCO in 1987 and the resulting surplus in indigenous aluminum production, the control over prices and distribution of aluminum was rendered redundant. Price and distribution controls were dispensed in 1989. Following decontrol prices rose immediately for almost all aluminum products except for high purity aluminum marketed by NALCO. Price hikes were highest for MALCO, in part, to make up for high losses it had suffered during the period of administered prices.

Table 2.7: Overview of Policies in the Aluminum Industry

Period	Policy	Specifics
1970	Aluminium Control Order	Dual Pricing, price control for electrical grade (EC) metals only.
1975	Distribution Control	50% of the output has to be produced as electrical grade metals.
Oct. 1978	Price and Distribution Control	Administered prices for all types of aluminum, distribution control continued.
Prior 1985	Export Control on Bauxite	
April 1985	Liberalization of Bauxite Export	
March 1989	Decontrol	Complete decontrol of distribution and prices
1990	Restrictive List	Aluminum items set from Open General Licences (OGL) to the Restrictive List of controlled imports and high customs duty
Source: Kalra (1992), CMIE (1996), Nayar (1990), Abrol (1985), Radharkrishnan (1987).		

Aluminum imports had to cover the gap between supply and demand until NALCO was taken on stream. The Mineral and Metals Trading Corporation (MMTC), was in charge of channeling import and distribution. The idea behind such a central agency was to ensure economies of scale as well as to protect consumers from wide fluctuations of international prices. After commissioning of NALCO, aluminum imports were put under 'Open General Licenses'. Customs duty on aluminum ingots were reduced and finally abolished with the complete decontrol in March 1989. The fall in the international price of aluminum during 1989 and later on led to increased imports of aluminum and a fear of overabundance of aluminum. In July 1989, the landed price of imported aluminum metal was lower than the price of indigenously produced aluminum. Consequently, in Feb. 1990, the government brought aluminum under the restricted list and increased the customs duty, which raised the costs for imported metals over the indigenous costs. Export of raw material, bauxite, was regulated until 1985 and released thereafter.

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, however, 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 still 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.

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. 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.

The three indices developed 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. Taking the inverse it 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 decided on the emphasis of 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 aluminum 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 aluminum industry are given in Appendix A. 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 Growth

Capital Productivity

Partial productivity growth estimates for capital are presented in Figure 3.1. Only few studies have been conducted on the aluminum sector in the past. All estimates reveal highly negative capital productivity growth independent of the time period considered. The study results range from –5.5% p.a. (Goldar, 1960-60) to –11.55% p.a. (CSO, 1969-77).

Labor Productivity

Historical estimates of labor productivity in the aluminum sector have been conducted by the same authors. They are displayed in Figure 3.2. Except for the study by Goldar, all past estimates show negative productivity growth. The CSO study reports labor productivity loss between –1.26% p.a. and –1.94% p.a. dependent on the subperiod considered. Ahluwalia reveals even higher productivity losses at –3.0% p.a. for the period 1959-85.

Capital-Labor Ratio

The overall trend in the aluminum industry has been towards capital deepening as indicated by the development of the capital-labor ratio. All previous studies support this finding. They show high growth of the capital-labor ratio ranging from 6.21% p.a. (Goldar, 1960-70) to a high of 9.61% p.a. (CSO, subperiod 1969-77).

3.1.1.2 Total Factor Productivity Growth

Total factor productivity change in the aluminum sector has been investigated in various studies. Except for a subperiod of Pradhan's study and except for our estimates which will be discussed in more detail below, all studies report negative development of total factor productivity for the past. Estimated productivity loss is highest in the CSO study for the subperiod 1969-77 at –10.1% p.a. and lowest for Pradhan's long range estimate, 1963-92, -0.2% p.a. It should be noted that Pradhan analyzes total productivity measures and not total factor productivity. Therefore, an immediate comparison with other studies tend to be difficult. Leaving aside Pradhan, the studies investigating total factor productivity reveal coherently high productivity loss of about –4% p.a. to about –10% p.a. independent of the time period considered. The remaining variations are due to differences in the length of the period considered and also due to differences in estimation procedures of input and output factors.

Figure 3.1: Estimates of Partial Productivity Growth: Capital

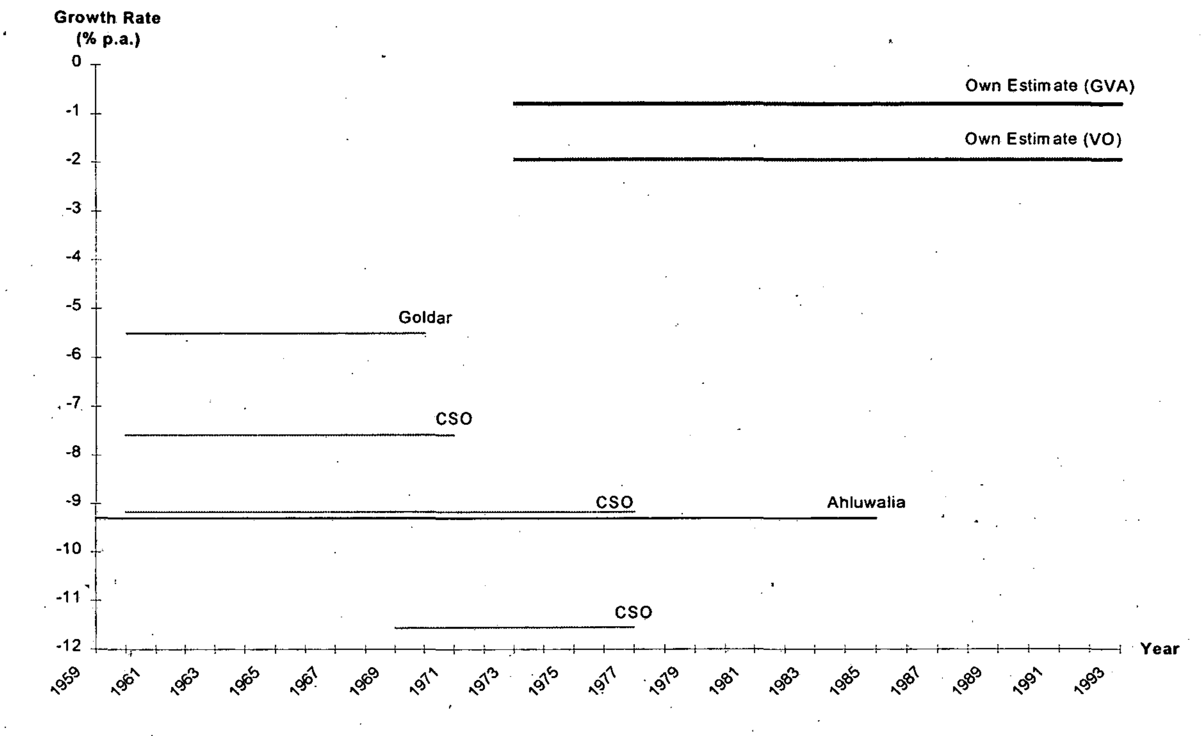


Figure 3.2: Estimates of Partial Productivity Growth: Labor

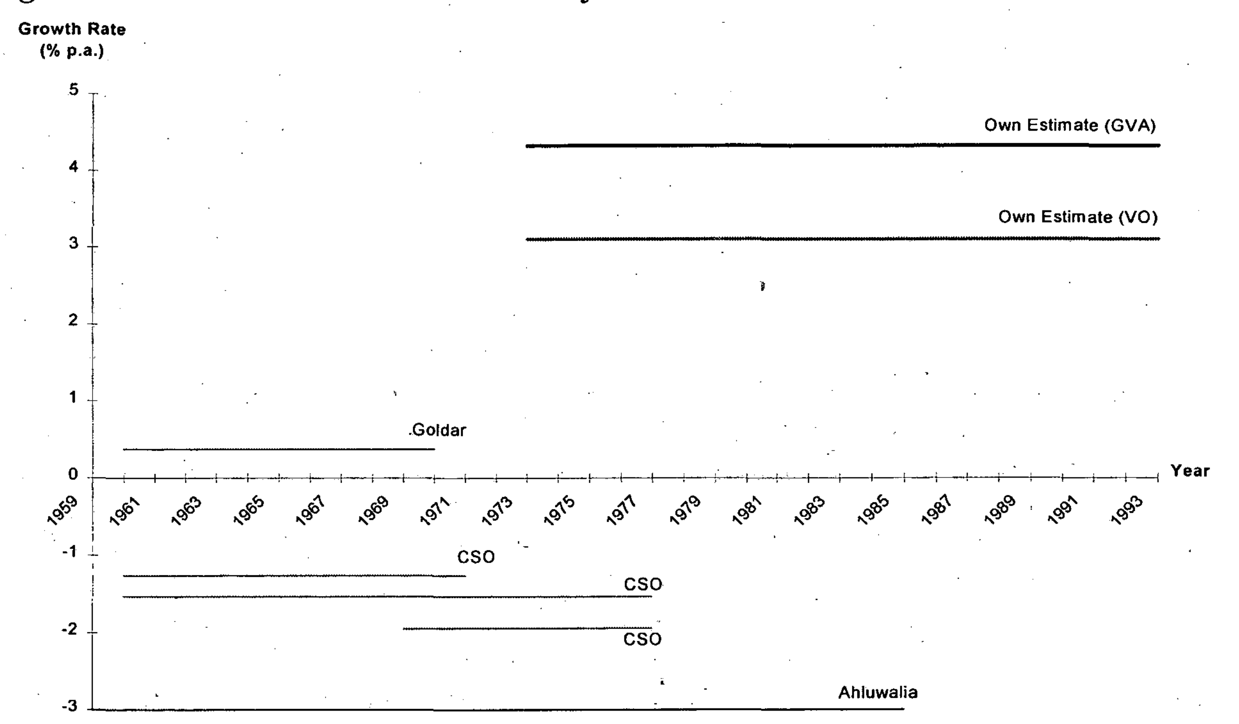


Figure 3.3: Estimates of Capital-Labor Ratio

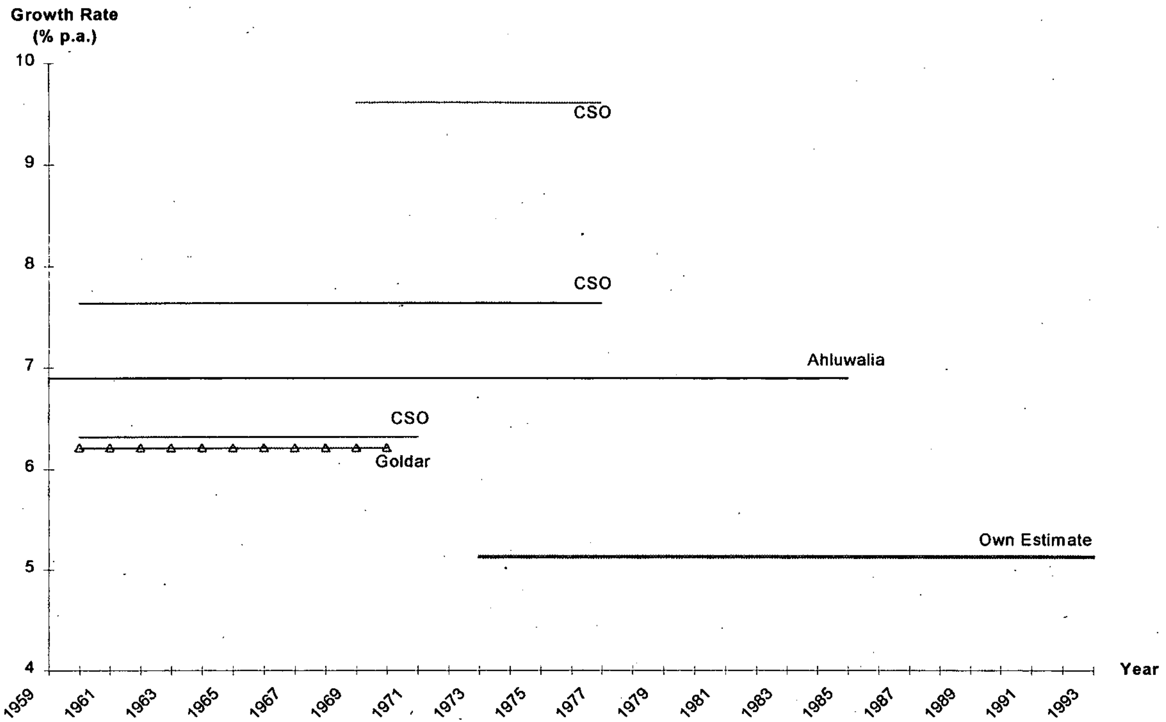
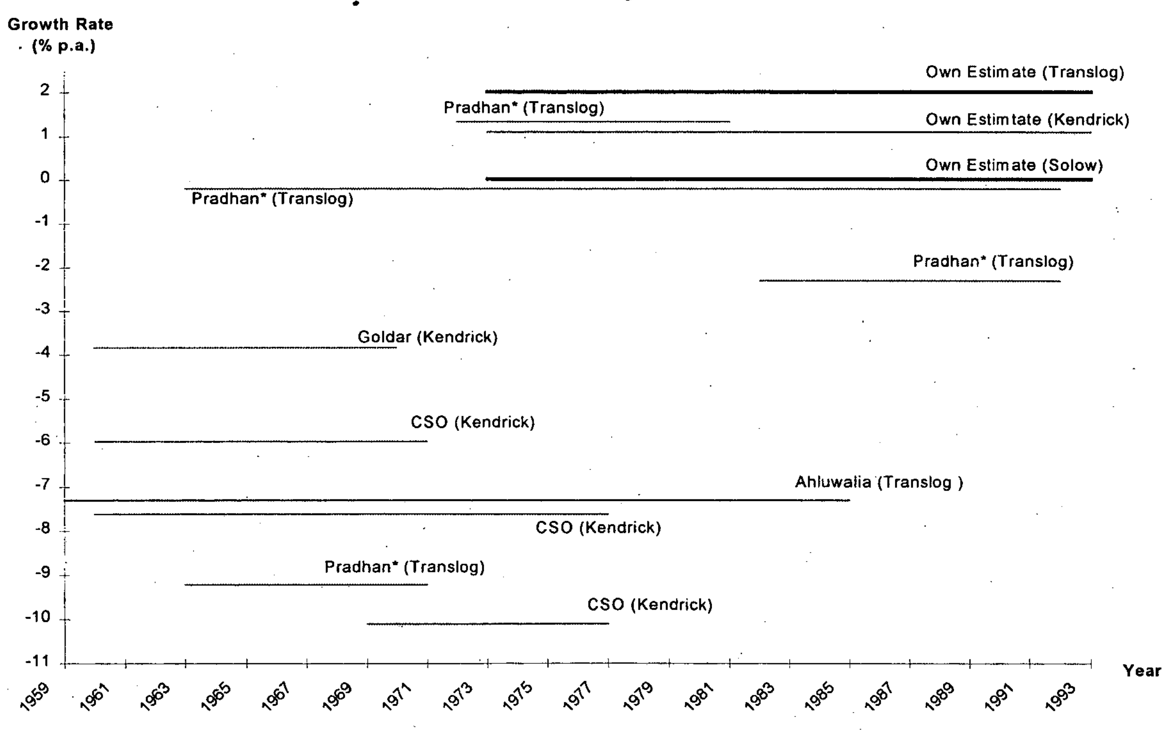


Figure 3.4: Estimates of Total Factor Productivity Growth



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

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, 1998a).

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 as presented in section 3.1.1. above. Figure 3.5 displays the partial productivities 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	-1.9	3.1	-1.9	-0.1	5.1	-0.8	4.3
1973-88	-3.1	3.0	-3.9	0.3	6.3	-1.5	4.7
1988-93	1.7	3.3	4.4	-1.2	1.6	1.5	3.2
Trend Rate 1973-93	-0.5*	3.9	-2.2	0.2*	4.4	0.05*	4.4

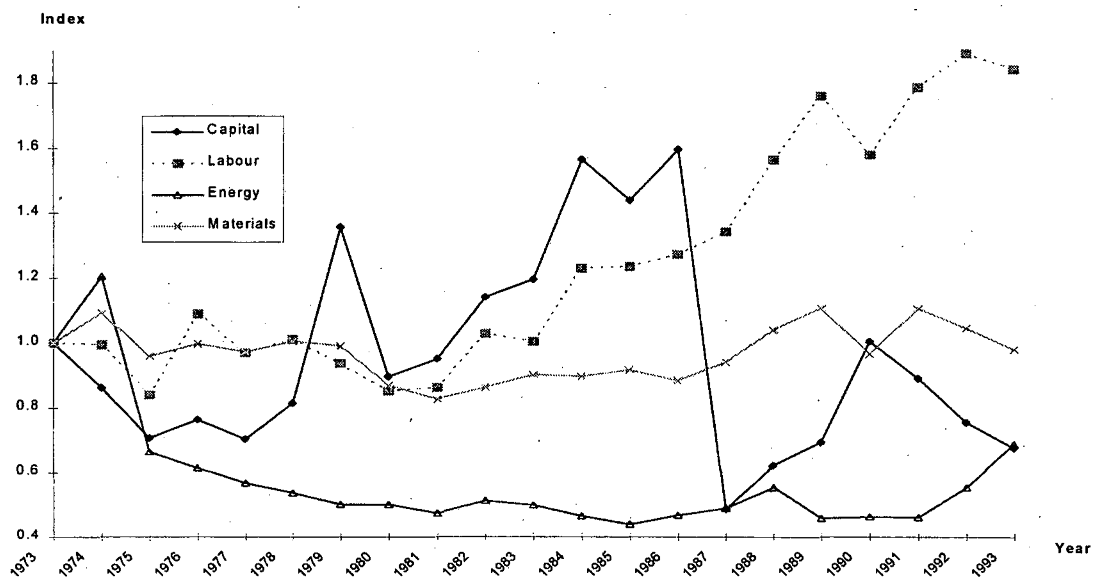
Note: Compound Growth; Trend Rate calculated as semi-logarithmic time trend, significant on 5% level unless otherwise indicated; * insignificant value.

The growth rates as well as the figure show significant changes in partial productivity over time. Capital productivity fluctuates the most showing an overall increasing trend until 1987. In 1987, with the commissioning of NALCO, a big capital intensive public entity, a tremendous downfall in capital productivity occurs. Yet, with production at NALCO significantly contributing to output, capital productivity recovers steadily until 1990 when it again starts to decrease. None of the other partial productivity figures shows a comparable response to the capacity addition in 1987.

Energy and material productivity show an almost U-shaped curve with productivity losses to the beginning/mid 1980s and gains thereafter. While energy productivity increases from 1985 on, with the exception of a drop in 1988, material productivity improvement starts earlier in 1981 and continues with few exceptions until 1991. Thereafter it declines significantly.

Labor productivity is on an upward path for almost all of the period between 1973 and 1993. Gains are substantial between 1983 and 1989, in particular following the start up of NALCO in 1987. After a downfall in 1990, labor productivity further increases until 1992. Over the whole time period, capital as well as energy and material productivity decrease at rates between -0.1% p.a. and –2.2% p.a. while labor productivity improves at 3.9% p.a.

Figure 3.5: Index of Partial Productivity (KLEM and Value of Output)
based on 1973-74 constant values (1973-74 = 1)



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. 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 high growth in the capital labor ratio at 4.4% p.a. Resources have shifted from labor to the use of capital over time.

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 the total factor productivity as measured by the Kendrick, Solow and Translog Index 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 index 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. Trend rates calculated as semi-logarithmic trends are also given.

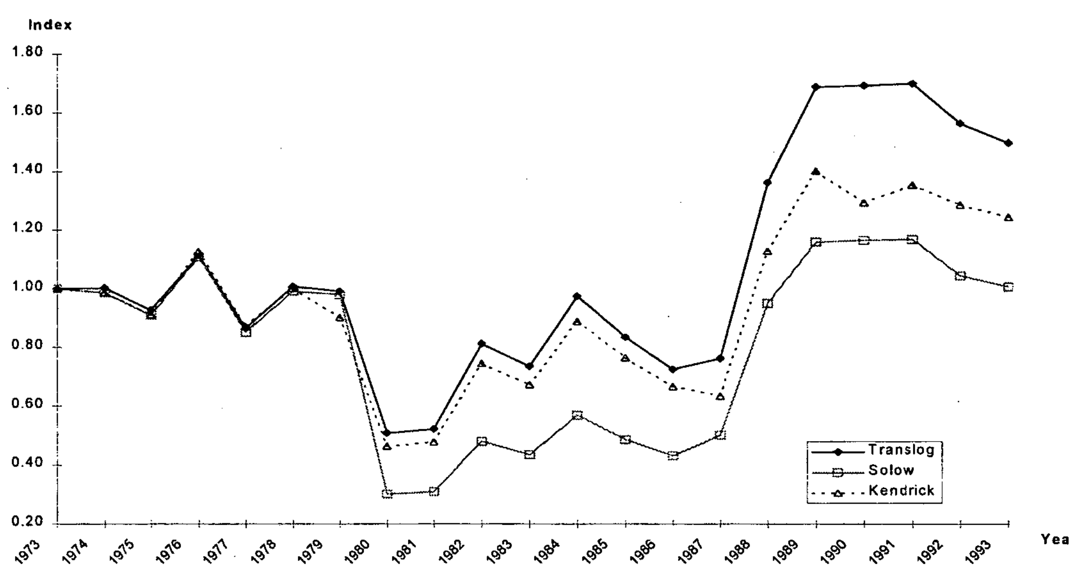
Table 3.2: Total Factor Productivity Growth
(selected time periods, per cent p.a.)

Growth	Translog	Solow	Kendrick
1973-93	2.0	0.03	1.1
1973-88	2.1	-0.3	0.8
1988-93	1.9	1.2	2.0
Trend Rate			
1973-93	2.9*	0.5	1.7

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

The three indices follow very similar patterns. The Kendrick index fluctuates in between the Translog and Solow index. Total factor productivity increased between 1973 and 1993. The Translog index renders the highest gain at 2.0%. The Kendrick index is slightly lower at 1.7%, while the Solow index is less optimistic accounting for a increase of only 0.5%. All three indices show only moderate change in the first part of the time period, 1973-79. In 1980, factor productivity drops substantially and slightly recovers thereafter. From 1987, again with the commissioning of NALCO, a steep increase in productivity can be observed which levels out around 1990 and results in a decline from 1991 on.

Figure 3.6: Index of Total Factor Productivity
based on 1973-74 constant values (1973-74 = 1)



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. The growth rates are calculated the same way as for total factor productivity.

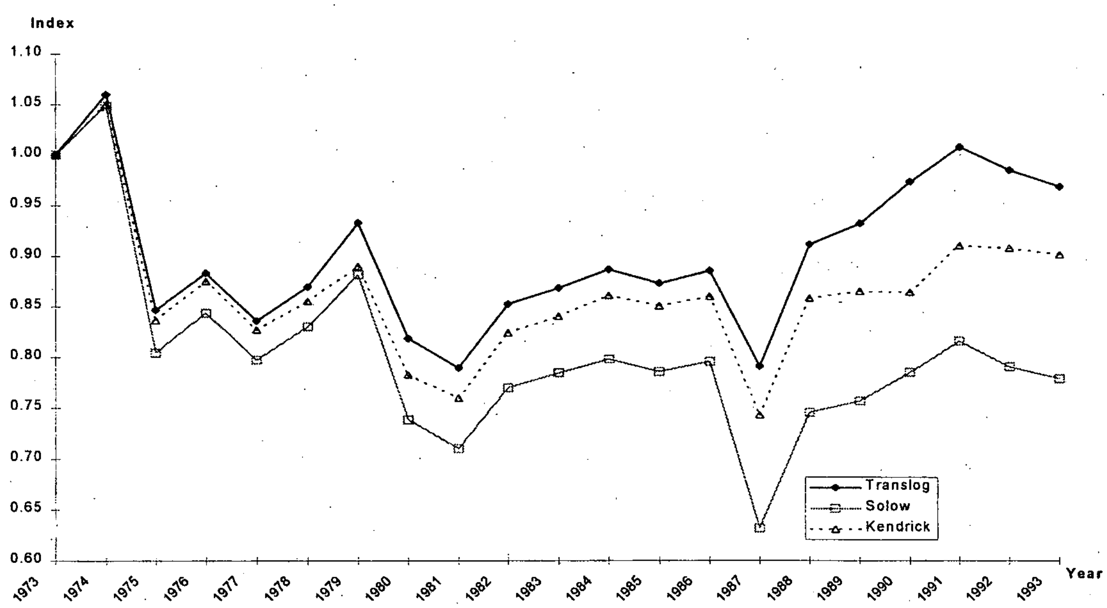
Table 3.3: Total Productivity Growth
(selected time periods, per cent p.a.)

Growth	Translog	Solow	Kendrick
1973-93	-0.2	-1.2	-0.5
1973-88	-0.6	-1.9	-1.0
1988-93	1.2	0.9	1.0
Trend Rate 1973-93	0.2*	-0.9	-0.2*

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

Table 3.3 and Figure 3.7 present the growth of the three indices and their evolution over time. The pattern differs slightly from total factor productivity growth. We observe decreasing growth for the two decades between 1973 and 1993 at –0.2% p.a. to –1.2% p.a. (depending on the index considered). The decrease is mainly due to negative development in the first decade where total productivity, although at fluctuating rates decreases substantially. Between 1981 and 1991, productivity improves with the exception of 1987, the year of the commissioning of the additional public plant, NALCO. From 1991 on, the trend has reversed again and productivity growth has been decreasing.

Figure 3.7: Index of Total Productivity
based on 1973-74 constant values (1973-74 = 1)



Considering the two subperiods, the era of total control and the era of decontrol, one observes negative development of productivity during the period of strict governmental control and positive productivity growth following deregulation. Between 1973 and 1988 total productivity declines by –0.6% p.a. to –1.94% p.a. (Translog and Solow index) while between 1988 and 1993 productivity growth is positive at 0.9% p.a. and 1.2% p.a. (Solow and Translog index respectively).

Decomposition of Growth of 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 includes technological change, learning, education, organization and management improvements etc. The two-folded base of growth in output can imply growth in output to be 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 shows that overall output in the aluminum sector measured as average exponential growth of gross output shows a quite positive trend over the period 1973-93 growing at a rate of 5.1%. However, the decomposition reveals that this positive development is solely due to increased use of factor inputs (5.3% growth in factor inputs). Productivity over the same time period decreases at –0.2% p.a.. The same is true for the subperiod 1973-88. Input growth at 7.7% p.a. drives output growth at 7.11% and at the same time offsets losses in productivity of –0.6% p.a. The period 1988-93 gives a reverse picture. With an annual growth of 1.2%, productivity growth is the only positive contributor to output which is actually declining during that time. The decline is due to decreased use of factor inputs (except for materials).

Table 3.4: Decomposition of Growth of Value of Output

Year	Growth (%) in Value of Output	Labor Input	Capital Input	Material Input	Energy Input	Total Input	Total Productivity
1973-93	5.1	0.2	0.8	2.5	1.7	5.3	-0.2
1973-88	7.1	0.3	1.4	3.4	2.6	7.7	-0.6
1988-93	-0.9	-0.2	-1.0	0.05	-1.0	-2.2	1.2

3.2 Econometric Analysis

3.2.1 Previous Studies

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.

3.2.2 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 resulting estimations 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[3] 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 used relatively more or less 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}
	-0.058	-0.006	-0.027	0.091	-0.001	-0.003	-0.002	0.006	-0.003
t-value	(-1.63)	(-0.59)	(-0.70)	(1.69)	(-1.24)	(-10.16)	(-1.54)	(3.99)	(-1.03)

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 material, labor and capital decrease with rising energy prices while the cost share of energy increases with rising energy prices. However, none of these values is statistically significant. The parameter b_{tt} indicates a slight but insignificant acceleration of technical change over time. As shown in the previous section productivity in the aluminum sector has been decreasing over time. Thus, a significant positive technical change parameter, as expressed by a significant negative value for b_{tt}, would indicate that this decline has been slowing down over time. Changes in productivity usually affect input factors differently. The technological change bias parameters here indicate a significant energy using as well as a significant labor saving bias. The resulting capital and material saving biases, however, are statistically insignificant. (Table 3.6).

Table 3.6: Technical Change Bias

	Materials	Energy	Labor	Capital
Technical Change	saving	using	saving	saving

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

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

change of one other or the same input factor. Own price elasticities have to be negative. 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 two input factors considered. It gives an increase in demand for 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	-0.731	LK	0.300	EK	0.050	MK	0.155
KL	0.135	LL	0.118	EL	0.045	ML	-0.079
KE	0.083	LE	0.165	EE	-0.389	ME	0.145
KM	0.514	LM	-0.583	EM	0.294	MM	-0.221

The price elasticities are shown in Table 3.7. All own price elasticities except for labor are negative. Among the own price elasticities, capital price elasticity is highest with –0.7, followed by energy price elasticity with –0.4, and material price elasticity with –0.2. Cross price elasticities indicate substitutional relationship for all input factors except material and labor which are complementary (Table 3.8). Thus, a rise in, for example, energy prices will lead to increased use of material, capital and labor inputs to substitute for the more expensive energy input. Among the input factors, the relationship between capital and material is most elastic. A 10% increase in material price would lead to a 5.1% increase in capital input while at the same time material use would decrease by 2.2%. However, it needs to be noted that with most resulting elasticities being relatively small, overall input factors are only moderately elastic.

Table 3.8: Elasticities of Substitution - Qualitative Overview

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

3.3 Discussion

The results gained and explained in the previous section need to be set in context of actual changes in both structural composition and in policies within the aluminum sector over the last 20 years to better understand the factors driving technological change and productivity growth.

As we have seen productivity in the aluminum sector has been slightly decreasing over the past. The decline was driven by a downfall in productivity in the mid 1970s and again around 1980. A slight recovery can be observed for the period between 1981 and 1986. The two most significant drops in productivity can be associated with the commissioning of first BALCO in 1975 and later NALCO in 1987. In both cases, capital productivity dropped instantly with the commissioning of the new plants as fixed capital inputs were fully accounted for in that year, while variable inputs such labor, material and energy inputs increased in closer connection to rise in output.

Between 1973 and 1988 output grew at an average of 7.1% p.a. This high growth was solely driven by increased use of input factors, as productivity was falling during that time period. Among the input factors the main driver was material inputs, followed by increased use of energy. Energy productivity was decreasing as more energy was needed to sustain output growth. Three out of the four operating aluminum plants were of old vintage (commissioned before 1970) and showed low capacity utilization in the 1980s. The oil price shock in 1979 affected the industry in so far as fuel oil and coal needed for calcination and power generation became more expensive. Total productivity declined substantially between 1979 and 1981.

Low scale of operation, high production costs that were not always covered by the retention price system as well shortages in energy inputs and interrupted power supply for plants depending on the state electricity system affected the industry negatively. On the other hand, ensured demand for their products and foreseeable returns on production due to price and distribution control provided certainty to the industry and allowed aluminum production to flourish.

Between 1987 and 1991, in response to the commissioning of NALCO and the subsequent decontrol of price and distribution of aluminum productivity accelerated at highest rates ever. Prices increased significantly following decontrol allowing firms to receive adequate returns on production. However, after an initial upward jump productivity as well as output (both physical and value of output) declined slightly in the early 1990s. Liberalization of import and low international prices for aluminum products led to a significant increase of imports during that time with probably negative effects on domestic production. In addition, overall economic growth slowed down in the early 1990s with macro-economic problems and unstable political conditions.

Technological change in the aluminum sector was accompanied by a significant energy using and labor savings bias. Import of such technologies as employed in the aluminum industry usually implies a labor savings bias as countries where technologies are imported from are not as labor abundant as India and saving labor input results in substantial total costs savings in these countries. In a country like India where labor is both abundant and inexpensive this feature is not necessarily wanted but has to be accepted with the imports of technology.

The development of energy prices is of particular interest in the highly energy intensive aluminum 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 further reduced. The analysis of inter-input substitution further reveals that energy input is quite sensitive to changes in energy prices. A 10% increase in energy price would reduce energy consumption by 3.9%. All other factors, material, capital and labor, are substitutes to energy use, i.e., demand for these factors would be amplified by an energy price increase. The substitutional relationship is strongest for material input where a 10% energy price increase would lead to an increase in labor input of 2.9% to compensate for the reduction in energy use. Yet, most other inter-input substitution possibilities are rather weak.

4. Future Development in the Aluminum Sector

4.1 Ongoing Changes

Demand is expected to further increase with emerging segments such as transportation and packaging. Projected consumption, production, import and export is presented in Table 4.1. Production is projected to increase at around 5.5% p.a. between 1997 and 2001, while demand is projected to increase at a higher rate of 7.2% p.a. Within the deregulated sector, international trade will assume a more important role. Exports are expected to pick up in the future growing at 6% p.a. With increasing demand, however, imports will also have to increase unless additional expansion is taking place. Imports, between 1997 and 2002 are projected to increase at 18%. Aluminum demand is projected to further increase to 1.06 million tonnes in 2006-07 and 1.25 million tonnes by 2009-10 (Roy et al., 1998).

Table 4.1: Projected Aluminum Production and Consumption (1997-2002) ('000 tonnes)

	1997-98	1998-99	1999-2000	2000-2001	2001-2002
Production	630	680	720	745	785
Import	65	55	90	120	135
Export	95	85	110	115	120
Consumption	600	650	700	750	800

Source: Roy et al. (1998).

With increasing application of aluminum for building, packaging and automobile components the user-wise composition of aluminum demand is expected to shift closer to the world average mix as presented in Section 2.3. In addition, the price for Indian aluminum is expected to be linked to international prices for aluminum metal in the future. So far, NALCO has already linked its output price to the London Metal Exchange (LME) price structure (Roy et al., 1998).

The Indian aluminum industry is hoped to be globally competitive after long years of 'infant industry' protection. However, in order to achieve and sustain competitiveness major investment in capacity expansion, retrofitting and efficiency improvements have to be undertaken. Reducing capital as well as power and fuel costs plays the major role in investment decision making. Various brownfield additions are expected in the near future for HINDALCO and INDAL. These additions will be based on state-of-the-art technology with low power consumption and reduced manpower requirement (Roy et al., 1998) Due to high capital costs for setting up new aluminum plants and additional costs for captive power units to ensure steady power supply, no greenfield venture for primary aluminum production has been envisaged since the successful commissioning of NALCO.

To reach a high level of capacity utilization and scale of operation, adequate power supply is of importance. Additional captive power units which present the only alternative to unreliable power supply from the State Electricity Boards are under consideration, in particular for units that do not possess large capacities for captive power generation (MALCO and INDAL). (Kalra, 1992)

4.2 Potentials for Energy Efficiency Improvement

4.2.1 India versus Best Practice

Table 4.2 presents energy savings potentials by comparing specific energy consumption in Indian aluminum plants with specific energy consumption in plants using best practice technology. The table shows that a marginal plant (i.e. the best existing plant) in India competes reasonably well with world best practice. Steam consumption at INDAL, for example, amounts to 2.4 tonne/tonne of alumina and is thus comparable to world best plants in Hungary and France. The lower end of Indian electricity and fuel oil consumption in alumina production also matches the upper end of best practice consumption. Furthermore, electricity consumption at smelters is comparable to international and best practice consumption. Best achievable energy consumption in India would be close to 13,000 kWh/tonne aluminum. World best electricity consumption in the electrolysis process could be as low as 12,800 kWh/tonne aluminum (e.g. for the Pechiney plant in Dunquerque or some of the newly built plants in Brazil). However, even these most efficient plants on average operate at above 13,000 kWh/tonne aluminum (Eichhammer, 1992). NALCO is the most efficient Indian plant with an electricity consumption of 14,500 kWh/tonne aluminum in the smelter process in 1996-97 (compared to about 15,500 kWh/tonne aluminum in 1994-95).

Table 4.2: Energy Consumption by Process: India versus Best Practice

	India	Best Practice
Alumina Production		
Steam (tonne/tonne alumina)	2.0-4.0	1.5-2.0
Electricity (kWh/tonne alumina)	250-550	200-250
Fuel Oil for Calcination (lit/tonne alumina)	80-110	60-80
Aluminum Production		
Electricity (kWh/tonne aluminum)	14,500-23,000	13,000 (12,800-17,500)*
Aluminum Fabrication		
Electricity (kWh/tonne)		
Rolling	1650-1800	775
Extrusion	900-1200	840
Drawing	1000-1700	840
Fuel Oil (lit/tonne)	50-60	22
Source: Roy et al. (1998).		

*ranges from most advanced plant to older plants. Average of 13,000 kWh/tonne is best comparable to Indian consumption.

Table 4.3 presents energy consumption for alumina and aluminum production for current Indian plants as well as for best practice plants as indicated by Das et al. (1998) and in comparison by Phylipsen et al. (1998). Das and Kandpal (1998) calculate actual specific energy consumption for alumina manufacturing at NALCO at 25.1 GJ/tonne aluminum which is about world average energy consumption (in 1993). BALCO and HINDALCO use 32.3 GJ/tonne aluminum for alumina manufacturing in 1994-95. According to Das and Kandpal (1998), the world's best plant consumes only 16.2 GJ/tonne aluminum, while Phylipsen et al. (1998) assume 20.2 GJ/tonne aluminum as a benchmark. Depending on the benchmark chosen, energy savings potentials of up to 40% could be envisioned for Indian alumina manufacturing in HINDALCO and other plants while NALCO could achieve another 20% of energy savings. Compared to the world best plant as identified by Das et al. (1998), the energy savings potential in alumina production would be as high as 35% for NALCO and 50% for other plants.

Table 4.3: Specific Energy Consumption in Aluminum Industry (India vs. Best Practice) **(GJ/tonne aluminum)**

	India (NALCO)	India (other plants)	Best Practice (Das et al., 1998)	Best Practice (Phylipsen et al., 1998)	
Alumina Production					
Final Energy	25.1	32.3	24.3 (16.2[a])	20.2[b]	
Aluminum Production					
Thermal Energy	4	0.8-2.5			
Electricity	52.2-56	55-65	46.8[c]	45[d]	
Total					
Thermal Energy				18.3	35[e]
Electricity				46.9	46.9
Final Energy	87	86-100		65.2	81.9
Energy Savings Potential				**5%-35%**	
Source: Roy et al. (1998); Das and Kandpal (1998); Phylipsen et al. (1998).					

Note: Assuming 1.93 t of alumina per tonne of aluminum.
[a]World best plant; [b]Thermal Energy: 18.3 GJ/ t aluminum, Electricity: 1.9 GJ/tonne aluminum; [c]Roy et al. (1998); [d]equivalent to 12,500 kWh/tonne aluminum; [e]including 13.9 GJ/tonne aluminum of feedstock energy for anode production.

Energy savings potentials in the smelter (conversion of alumina to aluminum) range from around 16% to 30%. In 1994-95, energy consumption during electrolysis was lowest in HINDALCO with 57 GJ/tonne aluminum. In 1996-97, NALCO's energy consumption was around 55 GJ/tonne aluminum. Other plants consume up to 65 GJ/tonne aluminum leading to higher savings potentials compared to the best practice energy consumption of 46.8 GJ/tonne aluminum (Roy et al., 1998) or 45 GJ/tonne aluminum (Phylipsen et al., 1998).

Total energy savings potentials are more difficult to identify. According to Phylipsen et al. (1998) energy consumption for anodes produced by aluminum companies should be taken into account. Anodes may be produced on site or be bought from other companies in which case they should not be counted in the energy consumption of the aluminum industry. For India, no distinction was made between anode production within the plant or outside the plant. Das et al. (1998) report that pre-baked anodes which reduce electricity consumption in the smelter are used in 60.3% of total Indian production capacity. However, they do not report on the energy requirements and location of anode production.

Comparing India's final energy consumption of 87 GJ/tonne aluminum at NALCO and 86-100 GJ/tonne aluminum at other plants to 65.2 GJ/tonne aluminum as best practice energy consumption excluding anode production and 81.9 GJ/tonne aluminum as best practice energy consumption including anode production shows that overall energy savings for Indian aluminum production could be as high as 35%. The calculated saving potential would be substantially higher if world best energy consumption as given for specific plants (numbers in parenthesis in Table 4.3) would be employed as a benchmark (Das et al., 1998).

4.2.2 Categories for Energy Efficiency Improvement

Roy et al. (1998) as well as Das et al. (1998) identify energy savings that could be achieved depending on the action taken. They distinguish a) improvement of monitoring and control leading to 2-3% energy conservation, b) retrofitting (improvements in existing equipment efficiency) resulting in 10-15% energy savings and c) adopting new and best available technology yielding 20-30% energy savings. Further energy savings would result from increased recycling of scrap since secondary aluminum production consumes only 5 to 6% of the energy needed for the production of primary metal. Considering the low generation efficiency in India, these savings are even more substantial on a primary energy basis. Specific energy conservation measures for different process steps in existing and new plants along with their possible benefits for energy consumption are shown in Appendix B.

Table 4.4: Energy Consumption by Plant and Process after Adoption of Conservation Measures

	Alumina (per tonne of alumina)			Smelter (per tonne of aluminum)	
	Coal (tonne)	Fuel Oil (kg)	Electricity (kWh)	Thermal Energy (GJ)	Electricity (kWh)
BALCO	0.43	90	390	1.26	16522
HINDALCO	0.77	60	282	2.51	14341
INDAL	-	200	255	0.84	16421
NALCO	0.55	70	333	4.19	14548

Source: Das and Kandpal (1998).

Notes: Fuel Oil for BALCO includes consumption for steam generation; INDAL does not use coal for steam generation. Numbers are based on Table 2.6 and adoption of conservation measures as outlined in Appendix B.

Das et al. (1998) estimate specific fuel consumption in different manufacturing steps after the adoption of such a typical set of retroffiting conservation measures as outlined in Appendix B (compare also Das and Kandpal, 1998). Table 4.4 shows that consumption of coal, fuel oil and electricity in the alumina plant would be around 20% compared to current consumption as shown in Table 2.6. The largest absolute savings would occur in the smelter plant where electricity consumption would be reduced by 1000-1500 kWh per tonne of aluminum, equivalent to 6 to 8% savings through the adoption of these energy saving measures. Total average energy savings in this particular case would roughly be around 10% (final energy).

The costs for these energy conservation measures vary. They range from negligible to several hundred million rupees and have to be weighted against the benefits they yield. The energy savings measures can be cost effective yielding net benefits over time depending on the discount rate employed. In general, investment costs for retrofitting and modernization efforts in existing plants are 25 to 35% lower than the costs of new ventures. (Roy et al., 1998)

4.2.3 Barriers to Energy Efficiency Improvement

Although most of the measures for energy efficiency improvement provide substantial energy savings at low or medium costs, only few measures have been or are being implemented in the Indian Aluminum industry. Barriers to energy efficiency improvement are of both general and firm specific nature, thus occurring at the macro and micro level of the economy.

Policy changes towards liberalization create uncertainty with regards to raw material and final product prices which influences producers behavior. In addition, in a capital scarce country like India capital intensive industries, as the aluminum industry, focus on reducing capital costs rather than being concerned about energy inputs. Energy costs, however, are not negligible. They account for 50-78% of the total production costs (Das et al., 1998; Roy et al, 1998, report lower energy costs at 35% of total production costs), and are the highest of all manufacturing sectors.

High to medium initial investment requirements associated with energy conservation measures plus additional investment cost for indispensable captive power generation place a burden on the capital scarce economy. Lack of financing capabilities, as well as lack of incentives and investment programs impede the implementation of such measures. Furthermore, since all technologies and equipment are manufactured by foreign producers, acquisition of such technology and equipment requires foreign exchange. Substantial outflows of foreign exchange, however, would place further pressure on the overall economy. Though, it should be noted that more and more collaboration agreements between up-to-date foreign and Indian manufactures have been established. For example, the expansion program for INDAL (which is partially owned by Alcan Aluminum of Canada) is based on a joint venture with a Norwegian company.

Lack of dissemination of information on energy-efficient technologies as well as specific information on savings and benefits of energy savings contribute further to the hesitation to improve energy efficiency.

4.3 Effects on Carbon Dioxide Emissions

Aluminum production leads to both direct and indirect carbon dioxide emissions. Fuel combustion is the major source of emissions while further carbon dioxide is released at the carbon anode during electrolysis. Based on the energy consumption given in Table 2.6, Das and Kandpal (1998) estimate carbon dioxide emissions assuming an optimistic electricity generation efficiency of 35% for coal based power plants. Their results are presented in Table 4.5. Emissions at INDAL are lowest due to the use of fuel oil instead of coal for steam generation. In India, carbon dioxide emissions from aluminum production (per unit of aluminum) are more than 6 times the emissions from the iron and steel sector (Schumacher and Sathaye, 1998).

Table 4.5: Carbon Dioxide Emissions by Plant and Process (tonne CO_2/tonne aluminum)

	BALCO	HINDALCO	INDAL	NALCO
Alumina Production	3.44	4.30	1.78	3.53
Aluminum Production				
Fuel Combustion*	16.75	14.43	16.31	14.77
Chemical Reaction	2.54	2.54	2.54	2.54
Total (tonne/tonne aluminum)	22.72	21.7	20.62	20.83
Source: Das and Kandpal (1998).				

Note: Power generation is based on coal with gross calorific values of 4500 kcal per kg, while fuel oil has a gross calorific value of 9600 kcal per kg. The alumina to aluminum ratio is assumed to be 1.93. *includes coal combustion for power generation that is used in the smelter and also emissions from the anode plant.

With total aluminum production of 0.49 million tonnes in 1992-93, carbon dioxide emissions amounted to 10.24 million tonnes in that year. By the year 2006-07, emissions are expected to increase to a total of 22.46 million tonnes if energy consumption was to be held on the 1992-93 level (frozen efficiency). With energy efficiency improvements as outlined above reductions in CO_2 emissions of about 8% can be achieved (Das and Kandpal, 1998). Carbon reduction possibilities as energy savings potentials differ by plant depending on the specific plant characteristics. According to Das and Kandpal's calculations they range from 7.1% for INDAL to 9.7% for BALCO. It is estimated that by the year 2006-07 a total of more than 2 million tonnes carbon dioxide emissions could be mitigated.

It should be noted that actual emissions reductions could be substantially higher due to the rather optimistic assumption on electricity generation efficiency as well as significant further potentials for reducing specific energy consumption to best practice energy consumption (compare Table 4.2 and 4.4).

5. Summary and Conclusions

In this report, we investigated India's aluminum 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 declined over time. The decrease was mainly driven by a decline in the 1970s when capacity utilization was low and the energy crisis hit India. From the early 1980s on and in particular after the commissioning of the urgently needed additional capacity at NALCO and subsequent sectoral liberalization, partial as well as total productivity increased substantially. Since 1991, however, the sector has again suffered a slight decline in accordance with overall economic recession.

We further pointed out 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 plant specific energy savings of 5 to 35% could be achieved. A typical energy conservation revamp as outlined above would lead to energy savings of about 10% as well as carbon emission reductions of about 8%. 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 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 probably place a hard burden on the industry. 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

Aluminum Historical Estimates

Author	Method/Measure	Source of Data	Period	Growth Rate
Ahluwalia (1986)	TFPG: TL	ASI	1959-85	-7.3
	PP: Capital			-9.3
	PP: Labor			-3.0
	Cap/Lab Ratio			6.9
CSO (1981)	TFPG: Kendrick	ASI	1960-77	-7.62
	PP: Capital			-9.17
	PP: Labor			-1.53
	Cap/Lab Ratio			7.64
	TFPG: Kendrick		1960-71	-5.96
	PP: Capital			-7.58
	PP: Labor			-1.26
	Cap/Lab Ratio			6.32
	TFPG: Kendrick		1969-77	-10.10
	PP: Capital			-11.55
	PP: Labor			-1.94
	Cap/Lab Ratio			9.61
Goldar (1986)	TFPG: Kendrick		1960-70	-3.83
	PP: Capital			-5.5
	PP: Labor			0.37
	Cap/Lab Ratio			6.21
Pradhan (1998)	TPG: TL		1963-92	-0.20
			1963-71	-9.21
			1972-81	1.33
			1982-92	-2.30
Source: Mongia and Sathaye (1998a)				

Note: Growth rates are per cent per annum, either compound annual growth rates, semi-log trend rates or simple average growth rates.
TFPG-Total Factor Productivity Growth, TPG-Total Productivity Growth

Appendix B

Energy Savings Measures by Process Step

Energy Form	Measure	Benefit
In Alumina Plants		
Steam	- Adoption of tube digester - Evaporation less technology	- low heat consumption by improved heat transfer - low digestion time - decreased evaporation equipment - low operating cost - reduces steam consumption by about 30% (tube digestion) and 10-15% (evaporation less technology)
Fuel Oil for Calcination	- Retrofitting rotary kilns (existing plants) - Replacement of rotary kilns with stationary calciners (new plants)	- fuel oil savings of up to 25% for existing plants and up to 40% for new plants - low operation and maintenance cost - better quality alumina - greater plant availability
Electricity	- Use of variable speed drives for major process pumps and large motors in the plant, improved control systems, sequential operation etc.	- reduced requirement in electrical power of up to 100 kWh/tonne alumina
In Aluminum Plants		
Electricity	- Modernization of Söderberg cells (existing plants) - Modernization of cells with pre-baked anodes (new and existing plants)	- savings of 1-2 kWh/kg electricity - savings of 1 kWh/kg electricity
Source: Roy et al. (1998); Das and Kandpal (1998).		

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