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Environmental Energy Technologies Division

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Abstract

Historical estimates of productivity growth in India's iron and steel 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 declined by 1.71% as indicated by the Translog index. Calculations of the Kendrick and Solow indices support this finding. Using a translog specification the econometric analysis reveals that technical progress in India's iron and steel sector has been biased towards the use of energy and material, while it has been capital and labor saving. The decline in productivity was caused largely by the protective policy regarding price and distribution of iron and steel as well as by large inefficiencies in public sector integrated steel plants. Will these trends continue into the future, particularly where energy use is concerned? Most likely they will not. We examine the current changes in structure and energy efficiency undergoing in the sector. Our analysis shows that with the liberalization of the iron and steel sector, the industry is rapidly moving towards world-best technology, which will result in fewer carbon emissions and more efficient energy use in existing and future plants.

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1. Introduction

The iron and steel 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 iron and steel 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 will introduce the iron and steel 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. This following we derive both statistical and econometric estimates of productivity growth for the iron and steel sector over time. For the statistical analysis we calculate 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 will then be 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 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 iron and steel industry structure. It will compare world best technologies to Indian technologies and identify potentials and barriers to the adoption of such efficiency improvements. A scenario analysis will conclude the report in highlighting the energy efficiency and productivity improvements that could be achieved by employing more efficient technologies.

2. Iron and Steel Industry

2.1 The Iron and Steel 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). The iron and steel sector holds a considerable share within these energy intensive industries. In 1993 it accounted for 46.5% of value of output within the six industries and for 7.8% in the manufacturing sector.

Table 2.1: Economic Indicators for the Iron and Steel Industry

	Unit	Iron and Steel	Aggregate of Six Energy Intensive Industries	Aggregate Manufacturing
Growth in Value of Output[1]				
Nominal				
1973-1993	% p.a.	16.4	16.4	15.1
1973-1985	% p.a.	17.7	17.5	14.9
1985-1991	% p.a.	13.0	15.7	15.1
1991-1993	% p.a.	18.9	12.2	16.2
Real				
1973-1993	% p.a.	7.6	7.9	7.4
1973-1985	% p.a.	7.8	8.0	7.6
1985-1991	% p.a.	6.2	10.1	6.9
1991-1993	% p.a.	10.2	0.4	7.3
In 1993-94:				
VO Share in Aggr. Manufacturing (nominal)	Sector VO/ Manuf. VO	7.8%	16.8%	100%
Sector Fuel Share in Aggr. Manuf. (nominal)	Sector Fuel/ Manuf. Fuel	13.2%	38.8%	100%
Share of Fuel Costs in Value of Output (nominal)	Sector Fuel/ Sector VO	11.5%	15.8%	6.8%
Source: Government of India, ASI: Summary Results for the Factory Sector (various years).				

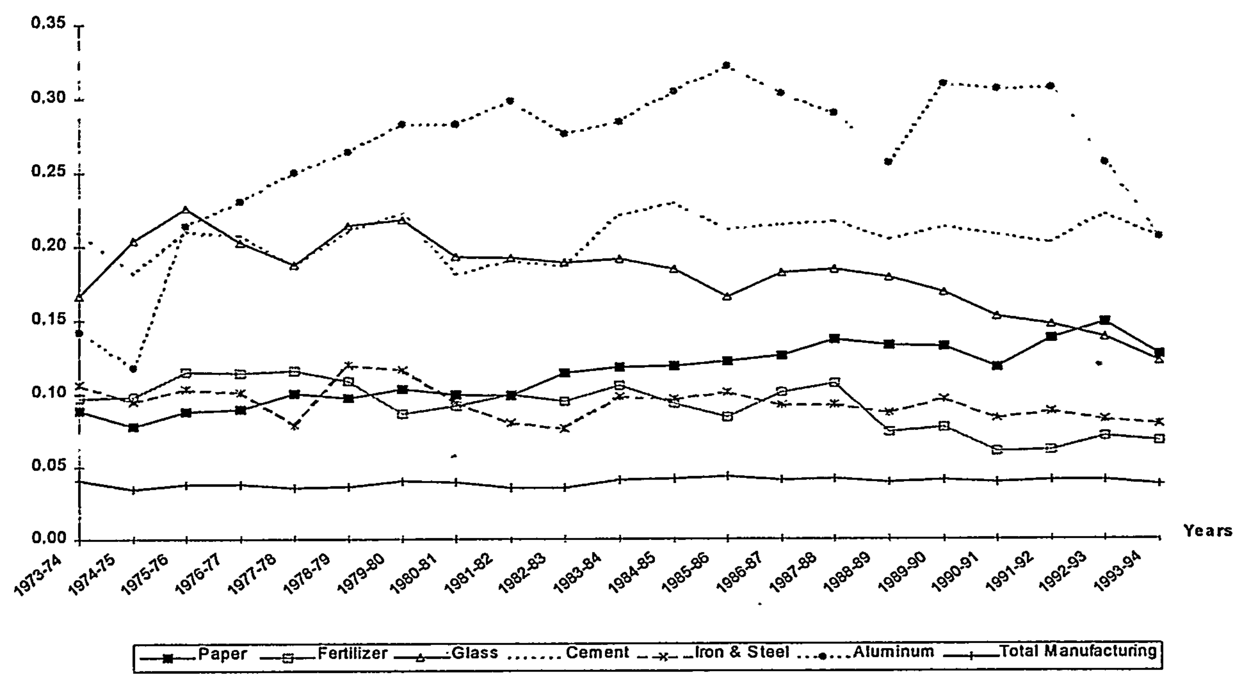
[1] calculated as exponential annual growth.

Production in the iron and steel sector has been increasing over the last 20 years. Over the study period 1973-1993 real VO increased by an average of 7.6% p.a. Following the fertilizer and cement industry, iron and steel shows third highest growth in the group of energy intensive industries. As seen in Table 2.1 growth of real value of output was stable at around 7.8% during the preliberalization period (1973-1985) and decreased significantly to 6.2% in the following period of economic liberalization[1] (1985-91)

[1] Economic reforms towards liberalization (up to 1991) and subsequent globalization in India are being reflected in flexible price and distribution policies, enhanced role of big business houses, increased competition both nationally and through international trade, technology transfer, reduction in subsidies etc. (Datt and Sundharam, 1998).

accounting for lower than average growth in both the group of six energy intensive industries and total manufacturing. In 1991, the liberalization process culminated and real value of output growth increased substantially by 10.2% until 1993. The upward trend is extraordinary compared to other energy intensive industries that generally experienced negative or very low positive growth during that period.

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



The iron and steel sector accounts for 13.2% 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 lowest in the iron and steel sector (11.5%). Fuel costs per unit of output are 27% less than the average for the six energy intensive industries. However, fuel costs per output are still 70% higher than the average of total manufacturing unit fuel costs. Figure 2.1 displays the energy intensity of the iron and steel sector in real values over time and in comparison to the other sectors. Besides fertilizer production, the iron and steel industry has been least energy intensive not only in 1993 but almost over the whole time period. Only in the early years of the time period under consideration iron and steel production was relatively more energy intensive. A peak can be observed in 1978/79. Overall, despite its fluctuating pattern the iron and steel industry shows a relatively stable trend in energy intensity.

2.2 Iron and Steel Process

Currently, there are two main routes for the production of steel: production of primary steel using iron ores and scrap and production of secondary steel using scrap as the main raw material. A wide variety of steel products are produced by the industry, ranging from slabs and ingots to thin sheets, which are used in turn by a large number of manufacturing industries. Steel production requires several steps that can be accomplished with different processes. Both the input material of each step and the process substantially affect the total energy consumed during production. The following step by step process description is borrowed from Worrell et al. (1997) and World Energy Council (1995).

2.2.1 Ore Concentration and Coke Production

The first step in the iron-making process is the concentration and pretreating of the iron ores. The energy consumed in this first step depends not only on the process used but also on the quality of the iron ore.

2.2.2 Ore Reduction

Ore is either pelletized or sintered as part of the production process. In the blast furnace route, which accounts for most of the global iron production, coke is used as the reducing agent and primary fuel.

2.2.3 Iron Making

In the iron-making step, ore is reduced to either pig iron or sponge iron. Pig iron production occurs either in blast furnaces where coke is the primary fuel or in the most advanced corex process using smelt reduction; sponge iron is produced in small-scale plants by direct reduction (DR) processes using syngas from fossil fuels, and it is reduced at temperatures below the melting point of iron, usually to ambient temperatures.

The conversion of ore into pig iron is the most energy-intensive stage of steel making. In a conventional integrated steel plant, pig iron is produced in a blast furnace, using coke in combination with injected coal, oil, or gas to reduce the sintered or pelletized iron ore to pig iron, which is principally used in its molten state. Limestone is added as a fluxing agent. Coke is either imported or is produced in coke ovens either on-site or off-site. Reduction of coke demand by injection of coal or other fuels such as oil or natural gas is beneficial because it reduces the energy consumed for coke making and the capital requirement for coke ovens. The amount of coal that can be injected depends on the process conditions of the blast furnace and the quality of the injected fuel (see e.g., Gudenau, 1990).

Blast furnaces are operated at various scales, ranging from the mini-blast furnaces in India with an annual capacity of 75 kt/unit (Singh, 1991), to the largest furnaces in Russia with an annual capacity of 4 Mt/year (Ulakhovich, et al., 1991). The furnaces' high temperature (about 1500°C) and strong reducing environment (high CO content) produce molten iron with approximately 4% dissolved carbon and some silicon, manganese, sulfur, and trace materials. By-products of the iron produced in blast furnaces include blast furnace gases (which can be used for heating purposes), electricity (if top gas-pressure-recovery turbines are installed), and slag (used as building material).

The COREX process using smelt reduction presents one of the most advanced ironmaking technologies available in the world. It combines coal gasification with reduction of iron oxides to produce pig iron and reusable gas as a by-product. The use of coking coal is unnecessary. COREX technology may be beneficial in saving energy and investment costs, while reducing environmental pollution. As of today, worldwide, only one operating COREX plant exists.

Sponge iron, produced by direct reduction (DR) processes, has different properties from pig iron. In the DR process, iron is produced by reducing the ores using syngas from different fossil fuels (mainly oil or natural gas; in India coal or gas based) in small-scale plants. DR iron (or sponge iron) serves as high quality alternative for scrap in secondary steelmaking.

2.2.4 Primary Steel Production

Steelmaking is the reduction of the amount of carbon in the hot iron metal to a level below 1.9% through the oxidation of carbon and silicon. Most primary steel is produced by two processes: open hearth furnace (OHF) and basic oxygen furnace (BOF). While OHF is an older technology and uses more energy, this process can also use more scrap than the BOF process. However, BOF process is rapidly replacing OHF worldwide because of its greater productivity and lower capital costs. In addition, this process needs no net input of energy and can even be a net energy exporter in the form of BOF-gas and steam. The process operates through the injection of oxygen, oxidizing the carbon in the hot metal. Several configurations exist depending on the way the oxygen is injected. The steel quality can be improved further by ladle refining processes used in the steel mill.

2.2.5 Secondary Steel

Secondary steel is produced in an electric arc furnace (EAF) or in an induction furnace (IF) using scrap. Induction furnaces are very unique to India. The secondary steel industry includes so-called "mini-mills", which make relatively simple products from low-priced scrap. In secondary steel production, the scrap is melted and refined, using a strong electric current. Several process variations exist, using either AC or DC currents, and fuels can be injected to reduce electricity use. Steel making based on external scrap (scrap from outside the steel sector) requires less than half as much primary energy as steel made from ore (Ross and Liu, 1991).

2.2.6 Casting

After raw steel is produced, it is cast in preparation for rolling and finishing. Casting can be a batch (ingots) or a continuous process (slabs, blooms, billets). The cast material can be sold as ingots or slabs to steel manufacturing industries. With ingot casting, liquid steel is cast into ingots that are cooled, then reheated and hot-rolled into slabs, blooms, or billets in a primary mill. The semi-finished steel is then cooled, descaled, and inspected before moving to rolling mills where it is again reheated. In continuous casting, the reheating step is eliminated because the molten steel is cast directly into slabs or blooms, which can be passed to the reheating furnace while hot. Continuous casting is therefore significantly more efficient in energy, yield, quality, and labor productivity as it reduces material loss and improves production time.

Ingot casting is the classical process and is rapidly being replaced by continuous casting machines (CCM). In 1993 around 70% of global crude steel production was cast continuously (IISI, 1994).

2.2.7 Rolling and Finishing

In the final production stages, the rough shapes produced by casting are rolled into thin sheets, bars, profiles (heavy sections and light profiles), or drawn into pipe or wire. Generally, the steel is first heated in a hot rolling mill to just below the melting point and then passed through heavy roller sections to reduce thickness. After hot rolling, some steel sheets are processed in cold rolling mills to produce even thinner sheets, which are used in numerous applications.

Finishing is the final production step, and may include a large number of different processes including annealing (heat treatment), pickling (removal of scale, coating, and oxides), and surface treatment. The amount of energy consumed in the finishing stage is small compared to other processes.

2.3 Iron and Steel Production in India

Although iron and steel is one of the most important industries in the Indian manufacturing sector, India is only the 15th largest steel producer in the world. Originating from the first set up of a single steel plant in 1911-12, the iron and steel sector included 7 integrated iron and steel plants in 1995-96. Due to the regulatory and political development of the sector only one of these plants is in private hands accounting for about 15% of total steel production. The integrated steel units usually use the blast furnace – basic oxygen/open hearth furnace process route for iron and steel production. In addition, there are about 180 secondary producers employing the electric arc furnace process. Another 500 mostly smaller units rely on other processes such as induction furnace process, melting by re-rollers, and ship breaking units.

Table 2.2 lists the different process routes and their shares in India and the world for 1993.

Table 2.2: Process Routes and their Shares in Production Volume (1993)

Product	Process	World Volume (Mt)	World Share (%)	India Volume (Mt)	India Share (%)
Iron	Blast Furnace	513	97	16	88
	Direct Reduction	19	3	2	12
Steel	Open Hearth Furnace	69	10	5	26
	Basic Oxygen Furnace	431	59	8	47
	Electric Arc Furnace	225	31	5	27
	Other	1	<1	0.04	<1

Source: IISI (1994, 1997).

Mt – million tonnes (metric), t – tonne (metric)

The economics of steel production in a conventional integrated steel plant is largely dictated by the iron-making operations. This is due to the high energy requirements for the conversion of iron ore into pig or sponge iron at the iron-making stage.

Table 2.3 presents pig iron and sponge iron production over the last 12 years. Production of sponge iron through the direct reduction/hot briquetted iron (HBI) process has grown from 0.05 to 4.20 Mt between 1983 and 1995. Due to constraints in the availability of scrap for secondary steel production sponge iron has increasingly been used as a high quality substitute for scrap in electric arc furnaces. Similarly, pig iron production has expanded continuously over the time horizon.

Table 2.3: Iron Production – Processwise **(million tonnes)**

Year	Pig Iron (Blast Furnace)	Sponge Iron (Direct Reduction/HBI)	Total
1983-84	9.16	0.05	9.21
1984-85	9.49	0.08	9.57
1985-86	9.84	0.10	9.94
1986-87	10.46	0.15	10.61
1987-88	10.81	0.19	11.00
1988-89	11.60	0.19	11.79
1989-90	11.93	0.26	12.19
1990-91	12.00	0.61	12.61
1991-92	14.18	1.15	15.33
1992-93	15.13	1.44	16.57
1993-94	15.67	2.21	17.88
1994-95	17.81	2.92	20.73
1995-96	19.03	4.20	23.23

Source: 1982-1985: IISI, Steel Statistical Yearbook (1992); 1986-1995: IISI, Steel Statistics of Developing Countries (1997).

Table 2.4 provides information on supply of crude steel in India split up by the different process types used. The primary steel producers hold the major share in India's overall steel production. The 7 large integrated steel plants account for more than 70% of India's steel production. Modern integrated steel units use the Blast Furnace/Basic Oxygen Furnace route for steel production. However, around 20% of total steel is still produced through the technologically less advanced Open Hearth Process (see Table 2.5). Some of the major sites have both basic oxygen and open hearth furnaces.

The secondary steel sector accounts for nearly 30% of India's crude steel production. The units producing secondary steel are usually relatively small of size. They were mostly set up in the early 1970s when suddenly the gap between demand and supply widened and more capacity was needed to meet local needs.

Table 2.4: Crude Steel Production – Processwise **(million tonnes)**

Year	Open Hearth Furnace	Basic Oxygen Furnace	Total Integrated Steel Plants	Electric Arc Furnace	Others	Total
1983-84	5.22	2.81	8.03	2.20	-	10.23
1984-85	4.86	3.44	8.30	2.26	-	10.56
1985-86	4.93	3.96	8.89	3.04	-	11.93
1986-87	4.66	4.34	9.00	3.20	0	12.20
1987-88	4.61	4.88	9.49	3.64	0	13.13
1988-89	4.88	5.64	10.52	3.79	0	14.31
1989-90	4.63	5.93	10.56	4.05	0	14.61
1990-91	4.68	6.17	10.85	4.11	0	14.96
1991-92	4.84	7.48	12.32	4.78	0	17.10
1992-93	4.76	8.25	13.01	5.11	0.001	18.12
1993-94	4.68	8.61	13.29	4.83	0.04	18.16
1994-95	4.93	9.36	14.29	4.97	0.02	19.28
1995-96	4.11	11.29	15.40	5.37	0	20.77

Source: 1982-1985: IISI, Steel Statistical Yearbook (1992); 1986-1995: Steel Statistics of Developing Countries, IISI (1997).

Table 2.5: Crude Steel Production Shares – Processwise **(percentage)**

Year	Open Hearth Furnace	Basic Oxygen Furnace	Electric Arc Furnace
1983-84	51.0	27.5	21.5
1985-86	41.3	33.2	25.5
1990-91	31.3	41.2	27.5
1994-95	25.6	48.6	25.8
1995-96	19.8	54.4	25.8

Source: 1982-1985: IISI, Steel Statistical Yearbook (1992); 1986-1995: Steel Statistics of Developing Countries, IISI (1997).

The electric arc furnace is still the most common process type to produce steel from scrap. The EAF industry in India has been mainly producing mild steel grades, although it would be more than equally well suited for producing alloy and special steel. As a result, mini steel plants have been challenged by economical problems over the past years. Many plants had to close down or reduce production leading to substantial idle capacity. The economic problems were mainly due to increased power tariffs in connection with high uncertainty about steady power supply, increases in cost and quality of essential inputs, particularly scrap, not only within India but also on the world market, and uneconomic sizes of furnaces.

With increasing competition in the steel sector both nationally and internationally the small steel plants, i.e. the EAF industry, are forced to go for modernization and expansion. EAF industries have started using upgraded technology, increasing the use of sponge iron through continuous feeding, scrap preheating and other modern and more efficient features. Furthermore, the secondary steel industry has more and more turned towards the combined use of mini blast furnaces (to supply hot metal) and electric arc furnaces. This combination basically presents a new approach to integrating steel production. However, although both process routes, direct reduction/mini blast furnace and electric arc furnace, present a cheaper and more easily available alternative they require substantially more energy input than scrap use or the blast furnace/basic oxygen route.

Another secondary steel producing technology, the induction furnace, has increasingly found application in India. Among all steel producing countries, India is probably the only country using it on a larger scale. The reorientation towards the use of induction furnace facilities for steel making started in the late 1970s or early 1980s. Today, some of the manufacturers even shut down their electric arc furnaces to install larger induction furnaces in the capacity range of 8-12 t. Overall, its share is still very small.

Total installed capacity for integrated steel plants and electric arc furnaces is shown in Table 2.6. Capacity underutilization as in other industrial sectors presents a major drawback in the Indian iron and steel sector. Capacity utilization has historically been fluctuating. From a low start in 1970-71 of 67% average capacity utilization, it increased to 84% in 1977-78 and declined again thereafter to around 75% in 1981-82. In recent years capacity utilization improved again to around 85% on average. It needs to be mentioned that the range of capacity utilization between plants is considerable. In 1970-71 it ranged from 40% to 86%, in 1977-78 two plants even registered capacity utilization of over 94%. The capacity utilization in mini steel plants is usually very low (around 56%) resulting largely from an inadequate supply of scrap and power. (Datt and Sundharam, 1998)

Table 2.6: Installed Capacity – Crude Steel **(million tonnes)**

Year	Integrated Steel Plants	Electric Arc Furnace Units	Total
1991-92	14.0	na	
1992-93	16.4	na	
1993-94	16.4	na	
1994-95	16.4	na	
1995-96	17.3	8.4	25.7

Source: Mishra (1998).

Capacity underutilization resulted in high costs of production and losses. According to Datt and Sundharam (1998) it was due to inadequate supply of coal and power, transport bottlenecks and other infrastructural constraints, lack of proper maintenance, poor management (e.g. caused by frequent changes in the top management of public sector plants), extensive labor troubles and in more recent years due to lack of demand by engineering industries like railway wagons etc. Furthermore, public units seemed to be particularly inefficient. They show continuous losses since they were set up additionally due to heavy investments on social overheads and administered prices and controlled distribution that did not allow these units to receive reasonable returns for their products.

As a result of the difficulties within the sector, India needed to import steel since 1970-71. However, the industry recovered significantly with the introduction of overall modernization as well as decontrol and liberalization efforts in both domestic steel production and import of steel items in the early 1990s. Due to higher domestic production and switch-over to higher value product mixes imports were limited over time. Today, India is able to increasingly participate in the world market - as an exporter as well as importer of steel products.

Table 2.7: Consumption and Production of Finished Steel **(million tonnes)**

Year	Production	Net Import	Consumption
1982-83	9.13	1.37	10.5
1983-84	8.50	1.36	9.86
1984-85	8.78	0.77	9.56
1985-86	10.03	0.73	10.76
1986-87	10.54	1.34	11.88
1987-88	11.95	0.86	12.81
1988-89	13.36	0.77	14.13
1989-90	13.4	0.28	14.12
1990-91	13.83	0.73	14.55
1991-92	14.63	0.23	14.86
1992-93	15.51	-0.08	15.42
1993-94	15.20	-0.28	14.92
1994-95	17.22	0.43	17.65

Source: Centre for Monitoring Indian Economy (1996).

Table 2.8: Casting Technologies for Steel Production in India – Output and Shares

Technology/Year		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Continuous casting	Mt	0.5	0.82	1.04	1.39	1.66	1.83	2.44	3.01	3.34	4.18	7.01
(incl. strip casting)	% Share	4.2	6.8	8.1	9.9	11.6	12.5	14.6	17.0	19.3	22.4	33.8
Ingot casting	Mt	11.44	11.28	11.81	12.58	12.61	12.81	14.29	14.69	13.93	14.45	13.71
	% Share	95.8	93.2	91.9	90.1	88.4	87.5	85.4	83.0	80.7	77.6	66.2

1985: World Steel Trade (1983-1993), OECD - 1986-1995: Steel Statistics of Developing Countries, IISI (1997).

Continuous casting presents the most efficient technology to-date. It is increasingly substituting ingot casting all around the world as well as in India (see Table 2.8). In Indian integrated steel plants continuous casting accounted for less than 10% of output in

1986-87. By 1991, however, it had increased its share to 14-15%. Generally, most of the integrated steel plants are expected to switch over to continuous casting by the end of the century. As far as mini steel plants are concerned, in 1986-87, 75% of the production was continuously cast. New mini plants set up in India have 90% of their steel production through continuous casting.

2.3.1 Raw Materials

In general, India is well equipped with iron ore reserves. Furthermore, iron ore and coal can be extracted in close proximity to each other. However, quality of both iron ore and coal is very low. India's iron ores have relatively high alumina and low iron contents which causes adverse slag chemistry. In addition, ores are less closely sized and contain larger amounts of undesirables fines than in other countries. Likewise, India's coal is of low grade. Containing high ash and being metallurgical the coal is less than ideally suited for making coke for the reduction of iron.

Both iron ore and coal quality, therefore, have to be improved to serve as suitable inputs for steel production. Different types of ore can be blended to overcome part of the problem and only ores specifically suited for the respective reduction process should be used. Moreover, domestic coal can be washed, precarbonized by stamp charging or partial briquetting for more efficient coke production. It can further be substituted by high quality imported coal.

The availability and quality of Indian scrap for secondary steel production is rather limited. Domestic scrap has to be supplemented by scrap imports which are subject to highly uncertain world market pricing. Additionally, electrical energy as a second major input to secondary steel production is associated with uncertainty regarding the security of supply and prices.

2.3.2 Energy Use

Primary sources of energy utilized in the iron and steel sector encompass coking coal, non-coking coal, liquid hydrocarbons, and electricity. Out of these coking coal holds the major share of energy used (65-80%). While coking coal, non-coking coal and liquid hydrocarbons are primarily used in integrated steel production, electricity by far presents the major input for steel making in mini plants using electric arc furnaces or induction furnaces.

Specific final energy consumption in India has reduced considerably in recent years. While in the 1980s final energy consumption had been on average 45 GJ/tcs (excluding energy used for coke making), in the early 1990s it had already declined to around 35 GJ/tcs and has since further decreased to an average 33 GJ/tcs in 1995-96. However, specific energy consumption in India is still considerably higher than in the industrialized world (ranging from 17.1 GJ/tcs (Netherlands) to 20 GJ/tcs (France) in 1994)[2] (IISI, 1996a).

Besides technology and process related factors there are several other general factors affecting specific energy consumption in steel plants. The product mix, for example, has impact on energy use. The manufacture of more complex and high quality products increases overall energy intensity. In addition there are factors specific to India that should be taken into account when trying to understand why specific energy consumption in Indian steel plants is higher. They include the quality of raw material that is available to Indian industries, the scale of operation, plant sizes and sizes of coke ovens, plant utilization factors, economic and political incentive structures for adoption of technology updates and modernization, and the installation of energy saving and recovery systems.

2.4 Past and Future Demand

Demand for steel products has almost continuously been higher than steel production in the past causing India to be a net importer of steel (Table 2.7). Due to various restrictive government regulations regarding distribution, pricing and importing of steel, consumption has to a significant extent been influenced by domestic availability of steel. In a liberalized economy consumption is expected to grow according to free market demand and no longer to be restricted by supply constraints. Steel as an input to the production of major capital goods, such as automobiles, railways, power plants etc. is highly dependent on the development of these sectors. Steel demand is therefore not only determined by the aggregate level of investment and industrial production but also by the allocation of resources across different sectors and their shares in total industrial production. (Pal, 1997)

Both gross domestic capital formation in the construction sector and gross domestic capital formation in machinery and equipment have been identified as major contributors to steel demand. Further variables include sectoral as well as overall GDP and demand for consumer durables. Based on these factors Pal (1997) predicts demand for finished steel products to increase significantly at an average of 9.5% from 20.4 Mt in 1996-97 to 33 Mt in 2001-02. Demand for pig iron is forecast to rise at an average 5% during the same time period.

2.5 Policy

The Indian iron and steel sector has been under strict government control for almost the whole period since independence. Government intervention took place in the form of both direct and indirect intervention. Direct intervention happened in the form of government control over distribution of available steel among consumers and indirect intervention took the form of price control and import levies.

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[2] It should be noted that for an exact comparison between countries specific energy consumption would need to be adjusted for the country specific product and technology mix.

After independence in 1947, the government took full control over the iron and steel sector and established a policy of restricting development of new integrated steel plants to the public sector. From then on first two and after conversion of IISCO to a public entity only one integrated steel company was privately owned. In 1959 the government formally approved the setting up of privately owned EAF based mini plants by modifying the Industrial Policy Resolution, 1956. The policy change was due to sustained shortage of steel in the Indian economy. Although these units expanded their capacity rapidly they could not make up for the consequent neglect of expansion in the public steel sector during that time. However, they contributed significantly to the availability of steel keeping the amount of steel imports relatively low.

Prices of different steel products were determined by the government and announced by the Joint Plant Committee (JPC), a body constituted in 1964 under the Iron and Steel Control Order. The Committee is headed by the Development Commissioner for Iron and Steel. All major steel plants and the railways are members of the JPC. However, not all steel items were under immediate control of JPC. Rerolling units, electric arc furnace units and alloy steel producers were allowed to fix their own prices for their products. From the main producers about 80% of production of the plants under the Steel Authority of India Limited (SAIL) and about 65% of the production of the private company (TISCO) were regulated by the JPC.

Prices were fixed by the JPC according to normative costs and certain levies like the Steel Development Fund (SFD), Engineering Goods Export Assistance Fund (EGEAF), JPC Cess, Freight Equalization Fund (FEF) etc. The SDF related to new development works and only applied to four large plants. JPC Cess was charged from consumers of steel for maintaining the JPC. Through the freight pooling system iron and steel materials were made available at a uniform price throughout the country. The price contained a freight component that was averaged over the country as a whole. The freight pooling system thus promoted equal industrial development all over the country. The distribution policy aimed at ensuring an equitable distribution among end-users and meeting the requirements of the priority sectors like Railways, Defense and Power. Together with the price policy the government wanted to ensure iron and steel availability to consumers according to their priority at reasonable prices throughout the country.

From 1972 on, due to impeded growth in the steel industry, the government introduced dual pricing in the iron and steel industry. Certain steel products such as heavy structurals, flats and railway materials were made available at low prices. For other products, prices were allowed to increase significantly. Such asymmetric fixed prices remained active for a long period. In 1982, the Bureau of Industrial Costs and Prices (BICP) officially observed what had been implied for a long time: Costs and prices of different categories of iron and steel did not show any systematic relationship under dual pricing. A comparison of actual and calculated 'normated' costs for each steel item revealed that only two items, i.e. heavy structurals and H.R. coils, had been priced adequately. Some products, such as pig iron and semi-finished steel, were substantially underpriced, others substantially overpriced.

In general, pig iron, semi-finished products and long products produced by the Integrated Steel Plants were underpriced. Prices for products, however, produced out of these semi-finished products were determined in the market. As a consequence many steel rerolling companies were set up that used cheap semi-finished products for producing final products that could be sold at free market prices. This way the rerolling units could gain enormous profits at the expense of the integrated steel industry.

Since 1992 the government has gradually decontrolled prices and distribution of steel. The new policy still includes control over distribution to priority sectors. Private production, however, has been totally decontrolled. The levies charged by JPC for the Steel Development Fund, Engineering Goods Exports Assistance Fund and JPC Cess will continue. Yet, freight equalization has been abandoned subject to certain conditions. Furthermore import duties have been substantially reduced by 20% and more on imports of various semi-finished and finished steel products.

In the progress of industrial development the government has also provided facilities to support mini-steel plants. These include (i) liberal import of melting scrap and sponge iron without import duty, (ii) free diversification into all grades of carbon and alloy steels, including stainless steel, (iii) installation of captive rolling units, (iv) addition of balancing facilities like continuous casting machines, heat treatment furnaces, etc.

Table 2.9: Overview of Policies Regarding the Iron and Steel Industry (1973 - 1993)

Period	Policy	Specifics
Before 1972	Price and Distribution Control	Price and Distribution Control determined by the Joint Plant Committee (JPC) (Iron and Steel Control Order). All major steel plants and railways are members of JPC. Not subject to price controls: rerolling units, electric arc furnace units, alloy steel producers.
	Levies	Levies are charged for Steel Development Fund (SFD), Engineering Goods Export Assistance Fund (EGEAF), JPC Cess, and Freight Equalization Fund (FEF).
1972	Dual Pricing	Heavy structurals, flats and railway materials (priority items) at low prices, other product prices allowed to increase significantly.
1982	Review of Dual Pricing	Review by Bureau of Industrial Costs and Prices
1992	Price and Distribution Decontrol	Distribution to priority sectors still under control, private production completely decontrolled. Levies to SDF, EGEAF and JPC Cess continue. Freight equalization abandoned.
	Reduction of Import Duties	Reduction of 20% and more on imports of various semi-finished and finished steel products.
Source: Datt and Sundharam (1998), Pal (1997), Sidhu (1983) and Ahluwalia (1985, 1991)		

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 iron and steel 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 iron and steel 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 capture 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 3.3. Except for the CSO study between 1969-77, estimates by various authors reveal negative capital productivity growth independent of the time period considered. Most study results range from –2.5% to –3.3% productivity loss per year. The CSO study reports capital productivity loss in this range, at -2.74% p.a., for the subperiod 1960-71 only. Over their whole study period, 1960-77, capital productivity decrease is lower at –0.81% p.a., while for the later years, 1969-77, the study reveals positive development of capital productivity, increasing at 2.07% p.a.

Mehta's results for the iron and steel sector differ substantially from all other authors' calculations. According to Mehta capital productivity loss reaches an enormous –22.8%. The study period, however, encompasses a very early time period, 1953-65. It might thus account for the immediate effects of India's independence from British colonialization in 1947.

Labor Productivity

As can be seen in Figure 3.4, estimates for labor productivity growth have been conducted by the same authors. Ahluwalia's, Goldar's and the CSO calculations result in positive productivity growth ranging from 0% to 1.48% p.a. for different time periods considered. Negative development has been reported by both, Kumari and Mehta. Kumari shows slight productivity loss at –0.74% for the period 1981-87, while Mehta again reveals a high decline of –5.2% p. a. for the earlier time period.

Capital-Labor Ratio

The overall trend in the iron and steel industry has been towards capital deepening as indicated by the development of the capital-labor ratio over time. All study results except one support this finding. The resulting estimates are more dispersed than the findings for capital and labor productivity. They range from 1.7% p.a. (CSO, 1960-77) to 5.1% p.a. (Ahluwalia, 1960-86). Again, Mehta, obtains a very different result: capital labor ratio grows at 16.9% in the post-independence period, 1953-65. In contrast, the CSO study shows a negative development for capital labor intensity, a decrease of –2.07% p.a. between 1969-77.

Figure 3.1: Estimates of Total Factor Productivity Growth

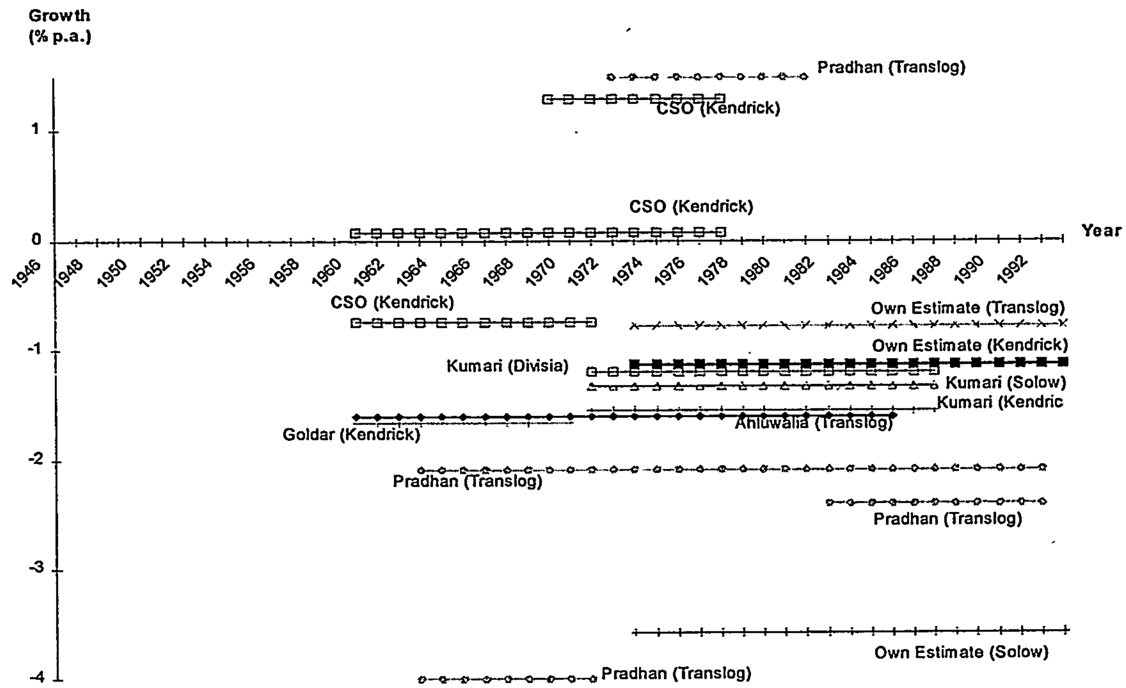


Figure 3.2: Estimates of Partial Productivity Growth: Capital

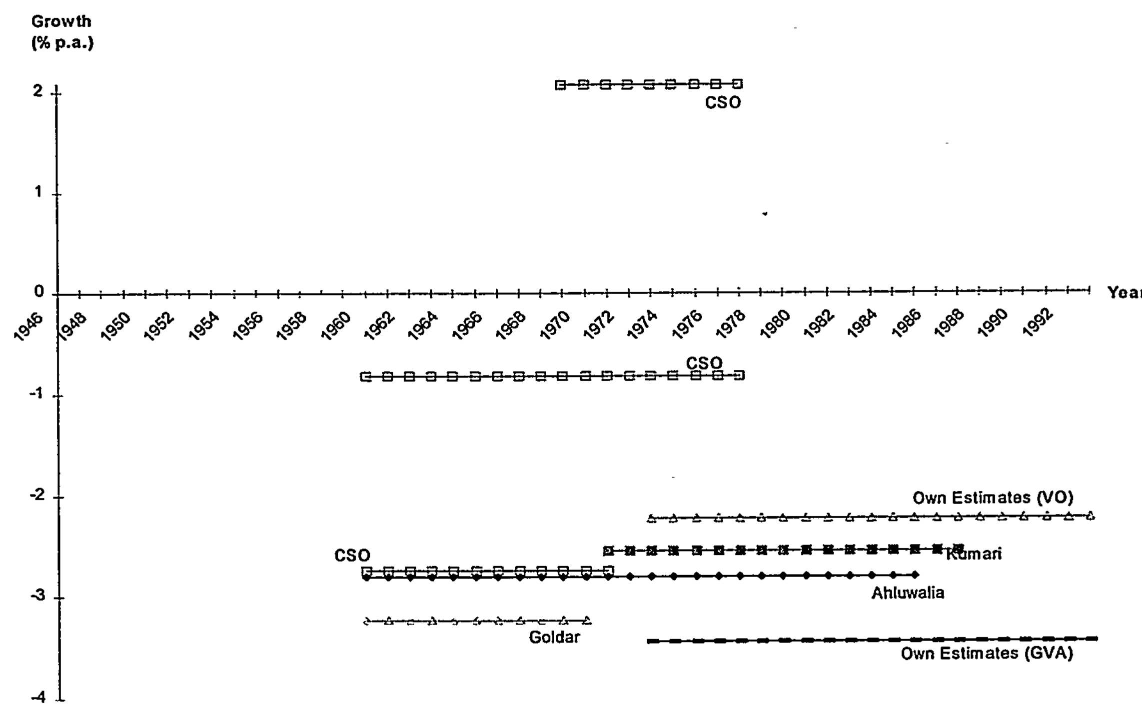
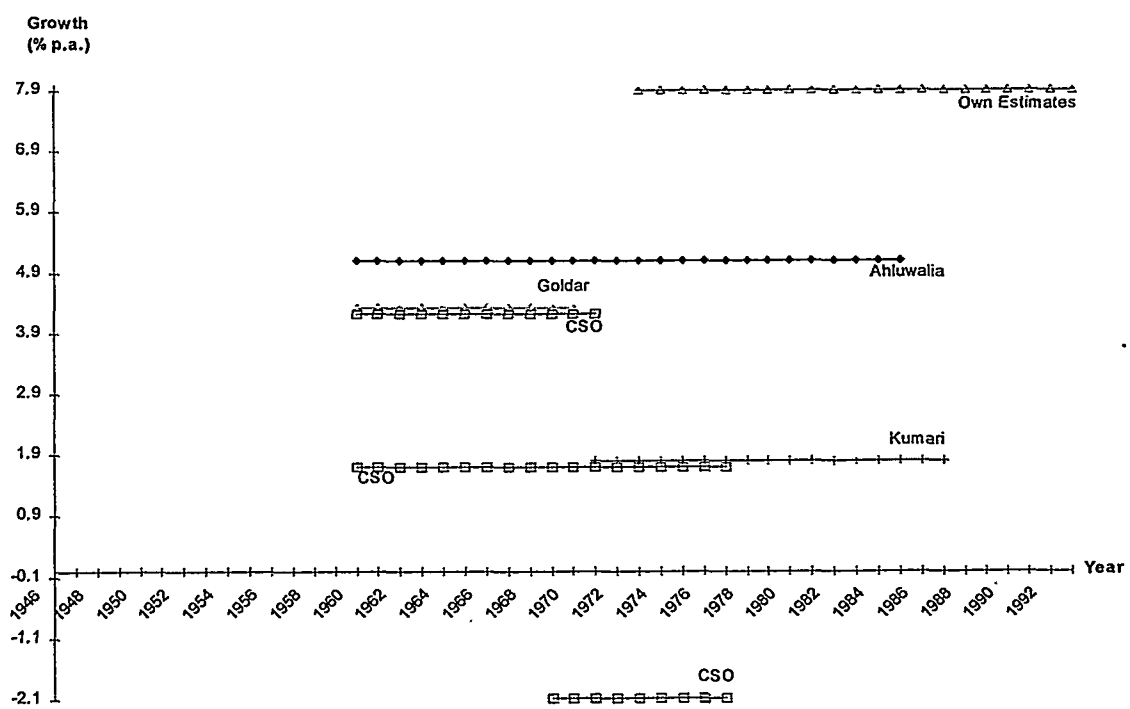


Figure 3.3: Estimates of Partial Productivity Growth: Labor

Figure 3.4: Estimates of Capital-Labor Ratio



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

3.1.1.2 Total Factor Productivity Growth

The development of total factor productivity in the iron and steel sector has been investigated in various studies. The results for different time periods are very consistent indicating negative changes in productivity over time except for two subperiods in the CSO study and one subperiod in a study by Pradhan. Leaving aside the study by Pradhan, the results for total factor productivity growth are very concentrated within a band of –0.7% to –1.66% independent of the approach used and the time horizon considered.

For the period immediately following independence, 1953-65, Mehta estimates a loss in total factor productivity at –6.3% employing the Solow index. The Kendrick index reveals a decline in productivity substantially higher at –22.9% p.a. for the same period. In contrast to these findings, productivity gains have been reported by CSO for the period 1960-77 at 0.07% p.a. and for the period 1969-77 at 1.29% p.a. as well as by Pradhan for the period 1972-81 at 1.49% p.a.

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, ASI. 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. 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.

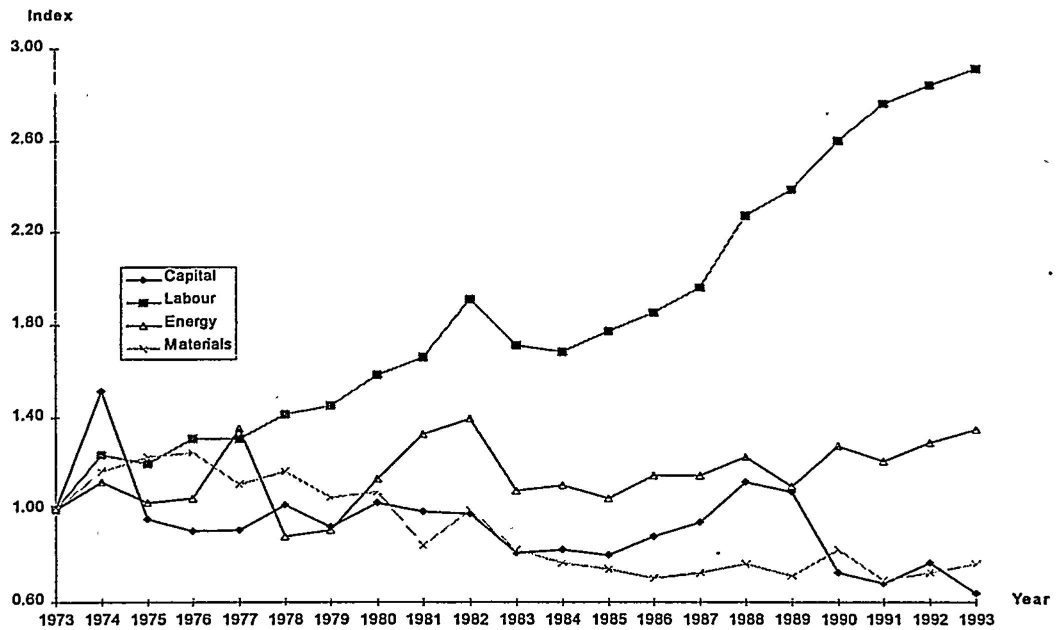
Over the whole time period (1973-93) both labor and energy productivity showed an increasing trend, while capital and material productivity followed a downward trend. The growth rates as well as the figure support changes in average productivity in the mid 1980s and again in 1991-92. Between 1973 and 1985 for example capital productivity decreased not as significantly as in the following period between 1985 and 1991. The downward trend intensified even more following 1991 when capital productivity decreased at an average of –3.41%. In contrast, material productivity in the same subperiods, though on average negative for the whole time period, increased substantially from –2.45% between 1973-85 to –1.17% between 1985-91 and finally to a positive development of 5.02% in the last three years. Similarly, energy productivity accelerated from period to period reaching a productivity gain of 5.59% between 1991-93. Labor productivity fluctuated in the time period from highly positive numbers to lower positive development. The middle period, 1985-91, stands out by its high increase in labor productivity of an average 7.68%.

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	-2.23	5.48	1.50	-1.34	7.89	-3.44	4.18
1973-85	-1.81	4.87	0.38	-2.45	6.81	-4.09	2.44
1985-91	-2.68	7.68	2.40	-1.17	10.64	-6.49	3.47
1991-93	-3.41	2.67	5.59	5.02	6.29	10.73	17.70
Trend Rate 1973-93	-1.87	4.84	0.98	-2.92	6.71	-3.72	2.99

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

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



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. Only in the last subperiod growth rates for GVA productivities differ substantially from Value of Output partial productivities, for capital productivity in both direction and magnitude of change while for labor productivity only in magnitude. This difference can be explained in view of a substantial increase in GVA between 1992-93, while at the same time VO decreased.

The growth in GVA in that last year offsets any productivity loss indicated by the VO measure.

The increase in labor productivity is to some extent the result of the process of capital deepening, the increasing use of capital per unit of labor, indicated by a high growth in the capital labor ratio at 6.29%. 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 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.

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

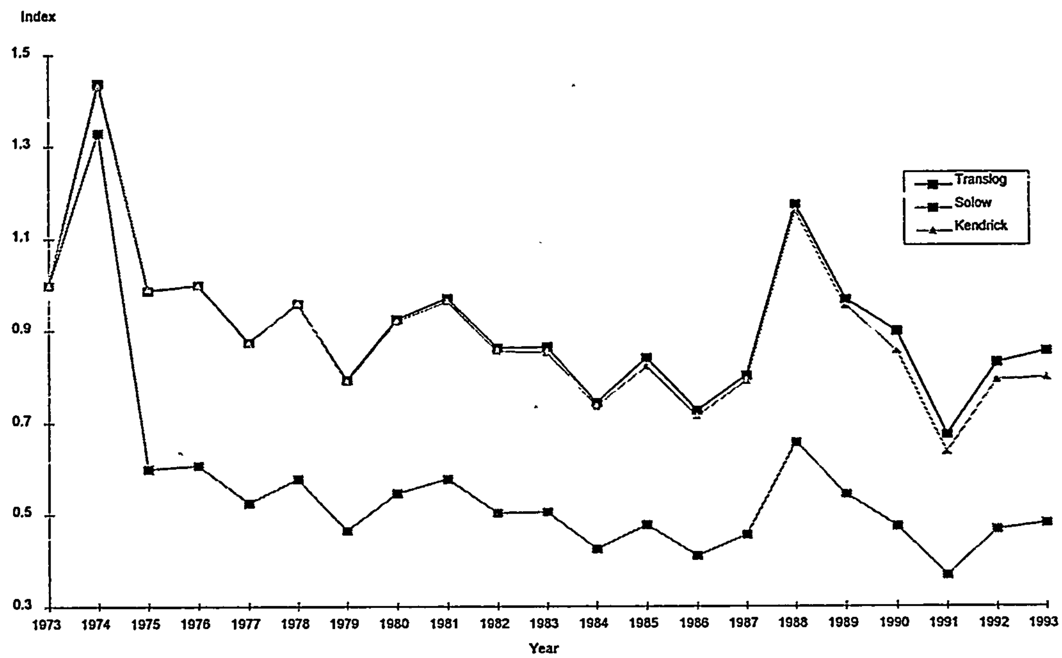
Growth	Translog	Solow	Kendrick
1973-93	-0.77	-3.58	-1.13
1973-85	-1.45	-6.00	-1.61
1985-91	-3.70	-4.27	-4.20
1991-93	12.08	14.77	11.95
Trend Rate 1973-93	-1.27	-2.99	-1.55

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

The three indices are related in their patters, roughly following parallel trends. The Translog and the Kendrick index are quite close in value while the Solow index reveals lower numbers. The growth rates for both the whole period as well as the subperiods are thus very similar for the Kendrick and Translog index. For the Solow index due to bigger changes on the base of lower values they show more extreme behavior.

For the whole time period all three indices show fluctuating patterns resulting in average losses of total factor productivity (Translog: -1.27%, Solow: -2.99%, Kendrick: -1.55%). The split up in three time periods supports the fluctuating behavior, indicating highest productivity losses in the second period, 1985-1991 (except for the Solow index which suffered a sharp drop in the initial period, 1973-85). Besides a peak in 1988, total factor productivity fell at average rates of 3.7% for the Translog index, -4.27% for the Solow index and –4.2% for the Kendrick index. Following a bottom point in 1991, total factor productivity recovered immensely growing at 11.95% (Kendrick) to 14.77% (Solow).

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



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

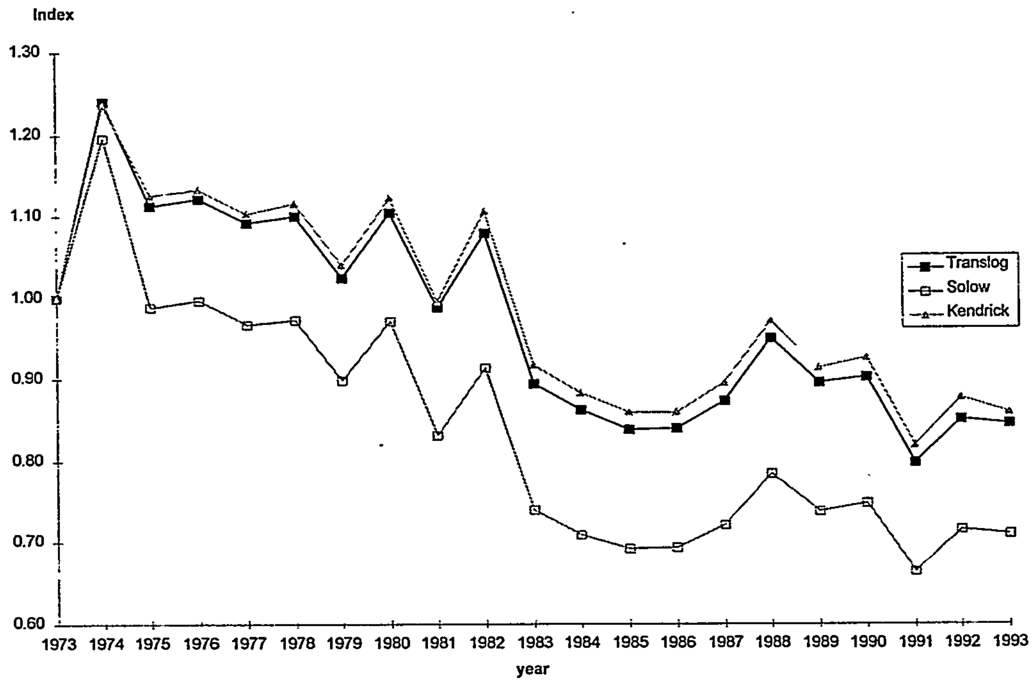
Growth	Translog	Solow	Kendrick
1973-93	-0.84	-1.70	-0.75
1973-85	-1.46	-3.03	-1.25
1985-91	-0.82	-0.66	-0.78
1991-93	2.83	3.34	2.41
Trend Rate 1973-93	-1.71	-2.39	-1.59

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

Table 3.3 and Figure 3.7 present the growth of the three indices and their evolution over time. Considering the whole period all three indices show negative growth of total productivity. (Translog: -1.71%, Kendrick: -1.59% and Solow: -2.39%). However, the division into three subperiods reveals a positive development over time. Between 1973-85 productivity loss was highest at –1.25% (Kendrick) to –3.03% (Solow). During the following subperiod, 1985-91, productivity loss slowed down to –0.66% (Solow) and –

0.82% (Translog) and finally turned around to considerable productivity gains of 2.41% (Kendrick) to 3.34% (Solow) in the period 1991-93.

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 shows that overall output in the iron and steel sector measured as average exponential growth of gross output followed a positive growth trend at 7.58% over the period 1973-93. However, the decomposition reveals that this positive development is solely due to increased use of factor inputs (8.41% growth in factor inputs). Productivity over the same time period declined at -0.84%. The same statement is true for the first two subperiods, the period of total control (1973-85) and the period of preliberalization (1985-91). Increases in inputs were the only drivers for increases in output that were further diminished by an actual loss in productivity during that time. Gains in productivity finally contributed to overall output growth in the period of liberalization, 1991-93. As total inputs did not increase significantly during that period (7.41%) compared to the previous periods, productivity growth reached a quite high share accounting for 2.83%, more than one fifth, of output growth (10.25%).

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	7.58	0.23	2.60	4.81	0.77	8.41	-0.84
1973-85	7.79	0.34	2.68	5.27	0.97	9.25	-1.46
1985-91	6.25	-0.03	2.29	4.35	0.46	7.07	-0.82
1991-93	10.25	0.38	3.03	3.46	0.55	7.41	2.83

Note: Exponential Growth Rates

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

Kumari (1972) estimates a Cobb Douglas and a CES production function for the Indian iron and steel sector using PE survey data for the period 1981-87. For both theoretical frameworks the estimates indicate growth of productivity, at a rate of 3.86% p.a. for the CD production function and at a rate of 4.2% p.a. for the CES production function setting.

Mehta (1980) as well estimates Cobb Douglas production functions for some energy intensive industries including the iron and steel industry. His sample period encompasses the years 1953 to 1965. Productivity in the iron and steel sector for his time period grows at 8.8% p.a. He further finds evidence of capital deepening in the production process but could not conclude any clear trend regarding efficiency improvements.

Bhardwaj (1987) analyzes plant level data for three plants and their aggregates for two time periods, 1962-89 and 1978-79. Estimating a translog cost function the aggregate estimation reveals a slight growth in productivity of 0.16% p.a. for the first period and a modestly higher growth of 0.59% p.a. for the other two-year period. The range of productivity change among the plants is quite large. For the longer time period results vary from a productivity loss of –0.02% for one plant (Rourkela) to a gain of 0.27% for another plant (Bhilai). Estimates for the second short period render the same relative pattern.

3.2.2 Own Estimates

Our results for the econometric estimation of productivity change and patterns of input substitution are derived 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. (1998). 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 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}
	0.028	-0.034	-0.060	0.066	0.006	-0.006	0.001	-0.002	0.002
t-value	(1.118)	(-5.798)	(-3.138)	(3.359)	(6.617)	(-28.26)	(1.342)	(-2.635)	(0.526)

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 labor and capital decrease with rising energy prices while the cost share of material increases with rising energy prices, the latter, however, being statistically insignificant. The parameter b_{tt} indicates a slight but insignificant deceleration of technical change over time. As shown in the previous section productivity in the iron and steel sector has been decreasing over time. Thus, a significant positive technical change parameter b_{tt} would indicate that this decline has been accelerating over time. Changes in productivity usually affect the input factors differently. The technological change bias parameters here indicate an insignificant capital and significant material using bias. At the same time technological change is statistically significant energy and labor saving (Table 3.6).

Table 3.6: Technical Change Bias

	Material	Energy	Labor	Capital
Technical Change	using	saving	saving	using

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

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 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	-0.907	LK	0.164	EK	-0.281	MK	0.271
KL	0.109	LL	-0.138	EL	-0.145	ML	0.028
KE	-0.244	LE	-0.191	EE	-0.382	ME	0.183
KM	1.043	LM	0.165	EM	0.808	MM	-0.482

The price elasticities are shown in Table 3.7. All own price elasticities are negative as required by theory. Among the own price elasticities, capital price elasticity is highest with –0.9, followed by material and energy price elasticity with –0.5 and –0.4 respectively. Cross price elasticities indicate complementary relationship between labor and energy and between capital and energy (Table 3.8). Thus, a rise in, for example, energy prices will lead to decreased use of labor and to a lesser extent of capital. However, material inputs will be more intensively used to substitute for the more expensive energy input. All other input factors are substitutional. The relationship between capital and material is most elastic. A 10% increase in material price would lead to an increase in capital input slightly more than one to one while at the same time material use would decrease by 5%.

Table 3.8: Elasticities of Substitution - Qualitative Overview

	Energy	Labor	Capital
Material	substitutes	substitutes	substitutes
Energy		complements	complements
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 policies within the iron and steel sector over the last 20 years to better understand the factors driving technological change and productivity growth.

As shown above productivity in the iron and steel sector has on average been decreasing between 1973 and 1993. However, a deceleration of productivity loss can be found over time with positive productive change towards the end of the study period. The split-up into three subperiods (1973-85, 1985-91 and 1991-93) is in accordance with structural and policy changes both in the economy as a whole as well as in the iron and steel sector. The first two time ranges cover the periods of total control and preliberalization of the economy while the last period is more specifically devoted to major liberalization measures introduced in the iron and steel sector.

Productivity loss was highest in the first subperiod under consideration. Output growth (7.6%) during that time was mainly driven by increased use of input factors, particularly capital and material. Inadequate supply of major input items, such as coal, power, scrap, ore and transportation placed substantial burden on the industry. The policy of price and distribution control with its two tier pricing system did not allow plants to receive adequate returns to their investment and caused substantial economic losses. Capacity utilization, as a result, was quite low over most of the period, although differing from plant to plant. According to the industrial policy statement from 1956 the iron and steel industry was completely reserved for the public sector. Besides the private companies already existing, no further private iron and steel plants were allowed to be set up. The public units generally suffered from inefficiencies in terms of poor and inefficient management, substantial investment burdens on social overheads, poor labor relations and overall slow and bureaucratic processing.

The following subperiod, 1985-91, does not show any significant policy and structural changes within the iron and steel sector. It is marked by more general measures towards liberalization in the economy. For example, licensed capacity was liberalized to allow industries to grow at a faster pace, to achieve economies of scale and to undertake modernization efforts. The government also freed the attitude towards small-scale sector units. Investment limits were increased and specific incentives for capacity expansion provided. Furthermore, for many products the concept of broad-banding was introduced.[4]

Some of these measures affected the iron and steel industry directly, such as the promotion of small scale units. Others exerted only indirect influence on iron and steel production. The concept of broad banding, for example, encouraged the diversification of production depending on factors such as market demand, raw material availability etc. Steel intensive industries such as the automobile industry took advantage of this policy change and increased and diversified production and thus their demand for steel.

Although the steel industry could not expand production to the extent necessary to meet demand the industry showed an improving trend. Between 1985 and 1988 total as well as individual factor productivity increased slightly. Yet, thereafter between 1988 and 1991 both total productivity and capital productivity once again followed a downward trend. Capital productivity declined throughout the whole study period at an accelerating rate.

[4] The concept of broad-banding refers to the product mix specific to manufacturers. Under broad-banding, licenses were issued in terms of broad categories to enable a given firm to manufacture any type of item covered as long as total production did not exceed the overall licensed capacity. (Datt and Sundharam, 1998)

Only a short upward trend in capital productivity can be observed between 1985 and 1988. A reason for the upward trend might be found in the increased set up of mini-steel plants that are generally less capital intensive. Although their individual capacity only accounted for a negligible expansion they provided an important supplement to steel production in total.

Two main cost factors, energy and transportation costs, imposed substantial burden on the industry. Costs for fuel, power, transportation as well as wages increased substantially over time mainly due to government regulations. Furthermore, coal was not easily available due to transportation constraints and was of low quality. In addition to these problems the government slowed down public investments in modernization, upgradation and expansion of the iron and steel sector. Investments laid out in the various plans were refrained due to other severe problems threatening economic wellbeing and development. Capital intensive industries had to give priority to investments in other sectors that were more directly related to basic needs.

The system of dual pricing and controlled distribution aimed at ensuring availability of steel at reasonable prices all over the country. Sectors, such as defense, railway and power, should be served on a priority base. The main products subject to regulated pricing were generally underpriced. However, free market prices for the remaining products could partly compensate for the losses obtained. Yet, as a consequence of the pricing structure many steel rerolling units used cheap and regulated semi-finished products for producing final products that could be sold at free market prices. Due to high profit margins these rerolling units were economically viable even at very low capacity utilization levels leading to the misallocation of otherwise importantly needed investment resources.

A turnaround can be observed after 1991 with the advent of major policy changes towards decontrol and liberalization of the iron and steel sector. The policy of decontrol introduced in 1992 has led to an adjustment of different prices and has implicitly induced improved capacity utilization of various plants. Domestic supply of steel has increased and the steel sector could recover considerably in recent years. Productivity increased at 2.8% for the first time substantially contributing to output growth of 10.3%. However, due to sustained growth in a few important steel intensive sectors like electricity, transport and latent demand for steel products prior to economic reforms the steel sector was not significantly affected.

The decomposition analysis allows to gain further insights on the contribution of both input factors and productivity change to output growth. We find that growth in output in the iron and steel sector was obtained mainly by increased use of factor inputs. Table 3.4 shows that growth in material inputs presents the driving factor of output growth for most of the time followed by growth in capital input. Overall, growth in input factors is quite stable over time. In terms of partial productivity gains energy and labor are outstanding. Energy productivity accelerated from subperiod to subperiod culminating in a productivity gain of 5.6% in 1991-93. This reflects the overall efforts undertaken in the iron and steel industry towards energy savings measures and technologies as already observed in the down fall of energy intensity (measured as fuel consumed over value of output) over the time horizon. Technological change in the iron and steel industry was accompanied by an energy savings bias.

The development of energy prices is of particular interest in an energy intensive industry like the iron and steel industry. An increase in energy prices through policy or world market changes would be counterbalanced by the industry's technological progress towards the savings of energy. With energy price increase, technological change and productivity growth could even be further enhanced. The analysis reveals that labor and capital inputs are complementary to energy use. An increase in energy prices would therefore additionally reduce demand for labor and capital. However, the inter-input substitution possibilities are weak. The estimated low values of elasticities point to little substitution possibilities.

4. Future Development of the Iron and Steel Sector

4.1 Ongoing Changes in the Iron and Steel Industry

The ongoing trend of expanding and modernizing steel production is expected to maintain in the future. Major investment and expansion projects are currently underway that will substantially increase the availability of steel on domestic as well as international markets. With the addition of two newly set up integrated steel plants, crude steel production capacity in the country will reach 30 Mt by the year 2000 (as opposed to 20.77 Mt as of 1995). Future production of crude steel has been estimated regressing crude steel production on a) GDP_{total} and b) $GDP_{industry}$. 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). Projections based on these assumptions as well as the average of the two production estimates are given in Table 4.1. Regressing crude steel production on $GDP_{iron\&steel}$ showed lower explanatory power and did not yield diverging predictions. Detailed regression results are presented in Appendix C.

Table 4.1: Projected Production of Iron & Steel **(Mt/annum)**

	Crude Steel Production (Mt/annum) based on		
Year	GDP_{total}	$GDP_{industry}$	Average
2001	28.71	29.53	29.12
2005	35.38	36.93	36.15
2010	45.95	49.07	47.51

Though currently the iron and steel sector seems to be on an upward path in a world of free market competition and prices, there are several drawbacks threatening the Indian industry. For example, the state of technology, despite the efforts towards modernization and upgradation, is still inferior to that in other countries. Low costs of primary inputs have so far led to low costs of production and economic viability of Indian steel. These advantages, however, may be eroded in the near future making Indian steel less competitive.

Therefore, technological progress and the adoption of more efficient and improved technologies need to continue supported by policy and economic incentives to the extent possible. Conversion towards the more efficient and modern basic oxygen furnace process in integrated steel plants and continuous casting of steel will have to be further promoted until the conversion process has been completed for all plants. Special attention regarding primary steel production has to be given to the iron making stage. The quality of the hot metal resulting from iron making is most important since it considerably affects subsequent operations. Silicon, phosphorous and sulfur contents of the hot metal should be low.

The iron making process involves two main steps: (i) preparation of materials, (ii) reduction of ore in blast furnace. While the technology, size and temperature of the furnace are important factors for increasing efficiency, the use of better prepared charge materials presents the single most important factor in improving blast furnaces productivity. Due to relatively low quality of iron ore in India, potentials in this area are high. At present, iron ore quality can be improved through blending of different types of ores, selecting suitable ore sources based on reduction testing, and final sizing of ore at the plant or by adequately controlling ore size.

Operating of the furnaces is being improved through various widely acknowledged methods, including the injection of auxiliary fuel in the blast furnace. Injection of auxiliary fuel reduces the demand for coke substantially. As coking presents another highly energy intensive and polluting process step this as well as other ongoing efforts regarding the improvement of coke making, such as blending, briquetting, preheating, stamp charging and selective crushing, are crucially important.

Most recently, construction of a COREX steel plant using smelt reduction has begun. With smelt reduction use of coking coal becomes unnecessary avoiding the significant problems associated with Indian coke production.

Secondary steel producers are currently undergoing essential changes towards efficiency and productivity gains as well. Economic viability of many of the plants is very low and they are facing severe crises and the danger of shut down. As scrap and electricity present the main inputs to secondary steel production improvement in the use of these is essential. Although import duty on scrap has been reduced from 12.5% initially to 10% and subsequently to 5% (CMIE, 1994), costs for scrap are still very high. Furthermore, captive power units that would prevent damages incurred by frequent power cuts as well as reduce power costs can mostly not be economically installed in small and mini plants. However, diversification of product mix towards higher quality steel products can help these plants to keep their market position. Typically, EAF processes could not produce highest sheet quality products due to high levels of residual elements in scrap that could not be eliminated. Yet, most recently secondary steel production units became available to produce high quality steel. Generally, demand for high-quality alloy steel products has been increasing in the recent past, while demand for mild steel products has been quite stagnant.

4.2 Potentials for Energy Efficiency Improvements

4.2.1 India versus Best Practice

Table 4.2 presents energy savings potentials by comparing specific energy consumption in Indian iron and steel plants with specific energy consumption in plants using world best technology (best practice). Total final specific energy consumption in India is the sum of fuels consumed and electricity purchased in the sector.

Best practice specific energy consumption is based on best practice weighting factors as developed by Worrell (1993, 1997) and shown in Appendix D. The weighting factors provide best specific energy consumption differentiated by technologies employed in different process steps. For iron production these are blast furnace and direct reduction; for steel production EAF and BOF; for rolling hot rolling and cold rolling. Best practice energy consumption in India can then be calculated combining these weights with India specific structural figures for iron and steel production (as presented in Tables 2.3 and 2.5).

Table 4.2: Specific Energy Consumption: India vs. Best Practice

		1992	1993	1994
India*:				
Electricity SEC	GJ/tcs	1.81	1.94	1.98
Fuel SEC	GJ/tcs	33.55	33.46	33.49
Total SEC (final)	GJ/tcs	35.36	35.39	35.47
Best Practice:**				
Electricity SEC	GJ/tcs	1.16	1.16	1.18
Savings Potential	%	36%	40%	40%
Fuel SEC	GJ/tcs	15.87	16.71	17.94
Savings Potential	%	53%	50%	46%
Total SEC (final)	GJ/tcs	17.03	17.87	19.12
Savings Potential	%	52%	49%	46%
EAF Share	%	28%	27%	26%

* Source: IEA (1998).

**Calculated based on India's sectoral structure and best practice weighting factors as given in Appendix D. Structural data from IISI (1997).

Worldwide, specific primary energy consumption is decreasing with rising scrap-based EAF production. This leads to a call for conversion towards EAF production to reduce overall energy intensity in the iron and steel sector. However, due to very low electricity generation, transmission and distribution, efficiency in India a shift to EAF might be counterproductive in resulting in higher primary energy demand than with BOF. Furthermore, due to scrap scarcity India's EAFs are increasingly using sponge iron as supplementary input next to scrap. Since the DRI/EAF route is more energy intensive than scrap based EAF steel production a positive effect of increased EAF production on best practice energy consumption might not be applicable to India. It is noteworthy that India's EAF share has not increased over the last few years.

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 upgradation of the power sector as well as increased establishment of onsite captive power generators that would at a minimum substantially reduce transmission and distribution losses. Naturally, improvement in generation efficiency will lead to lower primary specific energy consumption for the iron and steel sector.

4.2.2 Categories for Energy Efficiency Improvement

Potentials for energy efficiency improvements build to a large extent on ongoing changes in the iron and steel sector. They arise from improvement in input factors, from technology conversion and retrofitting as well as from recycling and waste heat recovery (see Appendix E for more detail). The potential in waste heat recovery, for example, is immense. Currently, over 50% of the energy used in integrated steel plants in India is lost. Losses occur as exhaust and by product gases that could be used for electricity generation or low heat steam production.

Appendix E further presents cost effective energy savings measures that have explicitly been analyzed for the Indian iron and steel industry. Payback periods for the investments that are mainly related to gas and heat recovery and improvement of input quality range between 1 and 13 years. For eight out of ten measures payback periods are less than 6 years, for five investment options even less than 3.5 years.

4.2.3 Barriers to Energy Efficiency Improvement

Although most of the measures for energy efficiency improvement are cost effective and provide net benefits within a certain time period, only few measures have been or are currently being implemented in the Indian iron and steel sector. 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[5]. In 1993-94, energy costs in relation to total input costs were as low as 6.5%. In contrast, energy costs in relation to production expenditures which do not capture total capital requirements accounted for 30% in 1996 (TERI, 1996). Lack of dissemination of information on energy efficient technologies as well as specific information on savings and benefits of energy savings potentials further contribute to the reluctance to energy efficiency improvement.

High to medium initial investment requirements associated with energy conservation measures place 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, since most of the more efficient and modern technologies and equipment cannot yet be manufactured in India, acquisition of such technology and equipment requires foreign exchange. Substantial outflows of foreign exchange, however, would place further pressure on the overall economy.

While in the 1970s and 1980s strict policy control on prices and distribution of iron and steel, although not necessarily efficient, provided a fixed planning schedule for investment decisions, nowadays, in a free market system returns to investment and profits are much more uncertain. Lack of confidence in the stability of the political system and of lending institutions presents an additional barrier to the adoption of innovations and modernization measures.

In addition, firm and technology specific barriers to energy efficiency improvements can be observed. Most of the mini steel plants are not operating on economies of scale implying that major investment projects can not economically be implemented. Some of the inefficiency in electric arc furnaces, for example, is only due to smaller furnace size, which on average is only 1/10th of the US electric arc furnace size. For the same reason, cogeneration and waste heat use facilities cannot be economically adopted in these plants.

Public sector integrated steel entities are usually old using obsolete and degraded technology. Many, particularly more advanced, energy efficiency options do not apply unless a complete conversion or retrofit of these technologies takes place. Furthermore, considering efficiency improvements in a broader context of the economy often reveals a tendency to substitute labor (manual work) by automation. In a labor abundant country

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[5] 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.

like India, these negative "external" effects reduce the feasibility of these options independent of cost benefit ratios.

4.3 Scenarios of Future Energy Efficiency

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

Engineering

Scenario 1 (Frozen Efficiency)

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 forecasts for future steel production, we calculate energy use for the year 2001, 2005 as well as 2010.

Scenario 2 (Best Practice)

The second scenario (Best Practice) assumes the adoption of world best (best practice) technology in India by a) the year 2001, b) the year 2005 and c) 2010. Using specific energy consumption values for world best technology as of today (Table 4.2) and forecasts for future steel production (Table 4.1), we calculate energy consumption for the industry in the year 2001, 2005 and 2010 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.

Scenario 3 (Best Practice Energy Price)

The third scenario (Best Practice Energy Price (BPEP)) assumes that by the year 2001 (2005 and 2010 respectively) energy consumption will be reduced to today's best practice energy consumption, as presented in Table 4.2, 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.

Results

Table 4.3 presents the results of the scenario analysis. The frozen efficiency (FE) case reveals that total final energy consumption in the iron and steel sector will reach 1030 PJ by the year 2001, 1279 PJ by 2005 and 1681 PJ by the year 2010, a more than 2.5 fold increase compared to the 1993 base year. Due to the assumption of no further improvements in energy intensity this change is solely driven by increases in crude steel production.

Table 4.3: Scenarios for Energy Consumption in 2001, 2005 and 2010

Scenarios			Engineering		Economics
			Scenario 1	Scenario 2	Scenario 3
Scenario for 2001		1993 Base	FE	Best Practice	BPEP (10%)
Electricity	GJ/tcs	1.94	1.94	1.16	na
Fuel	GJ/tcs	33.46	33.46	16.71	na
Specific Final Energy Consumption	GJ/tcs	35.39	35.39	17.87	17.89
Crude Steel Production	Mt	18.16	29.12	29.12	29.12
Total Final Energy Consumption	PJ	642.6	1030.4	520.4	521.0
Scenario for 2005		1993 Base	FE	Best Practice	BPEP (6.6%)
Electricity	GJ/tcs	1.94	1.94	1.16	na
Fuel	GJ/tcs	33.46	33.46	16.71	na
Specific Final Energy Consumption	GJ/tcs	35.39	35.39	17.87	17.70
Crude Steel Production	Mt	18.16	36.15	36.15	36.15
Total Final Energy Consumption	PJ	642.6	1279.2	646.0	639.9
Scenario for 2010		1993 Base	FE	Best Practice	BPEP (4.7%)
Electricity	GJ/tcs	1.94	1.94	1.16	na
Fuel	GJ/tcs	33.46	33.46	16.71	na
Specific Final Energy Consumption	GJ/tcs	35.39	35.39	17.87	17.74
Crude Steel Production	Mt	18.16	47.51	47.51	47.51
Total Final Energy Consumption	PJ	642.6	1681.1	849.0	842.9

na – not applicable

The Best Practice scenario shows that energy consumption could be reduced by more than half compared to the frozen efficiency (FE) case if world best technology as of today would be adopted by the year 2001, 2005 and 2010 respectively. The analysis further reveals that by adopting today's best practice technology in 2001 and 2005 improvements in energy efficiency would even offset increases in the activity level. Despite enhanced crude steel production of 60% by 2001 and a doubling by 2005 a net reduction of energy consumption of 19% for adoption of best practice technology by the year 2001 and the 1993 base level of energy consumption for adoption by 2005 would be attained. In the longer run (2010) increases in production activity together with efficiency improvement lead to a total final energy consumption of 849 PJ, a mere 32% increase compared to the 1993 base level.

The economic analysis focuses on price policies to achieve reduction targets. It considers the effects of changes in the price of energy 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 10%, 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 2005 (2010 respectively) reveals that a lower relative energy price increase of 6.6% p.a. (4.7% p.a. respectively) would be needed for achieving best practice energy consumption by means of energy price policies alone. Consequently, the BPEP scenario approves that, considering the nature of technological change in India's iron and steel 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.

Several comments should be acknowledged regarding the scenario analysis. Firstly, the assumption of adoption of best practice technology by the year 2001, 2005, or 2010 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 iron and steel 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. Energy is the single largest source of carbon dioxide emissions in the iron and steel sector contributing to global environmental problems. Reducing energy intensity is therefore not only beneficial in saving scarce resources and input costs, but also in reducing carbon emissions and thus mitigating global climate change.

Carbon dioxide emissions from different fuels have been calculated as presented in Table 4.4. For India, they are based on total energy consumed in the iron and steel sector differentiated by fuel type (IEA, 1998). Best practice emissions calculations are based on best practice energy consumption as presented in Chapter 4.2.1, assuming use of coke in sinter plants, blast furnaces as well as to 50% in pellet plants. The remaining processes are assumed to use natural gas (gas based case), except for EAF-slab which is assumed to be based on the use of natural gas (80%) and coal (20%).

Table 4.4: Carbon Dioxide Emissions: India vs. Best Practice*

		1993	1994	1995
India:	tCO_2/tcs	3.30	3.32	3.13
	Mt CO_2	59.94	63.93	65.00
Best Practice:				
Gas based	tCO_2/tcs	1.73	1.83	1.85
	Mt CO_2	31.32	35.50	38.50
Savings Potential	%	47.7%	44.8%	40.8%
Petroleum based	tCO_2/tcs	1.81	1.92	1.96
	Mt CO_2	32.82	37.03	40.60
Savings Potential	%	45.2%	42.1%	37.5%

*Calculated based on India's sectoral structure (IISI, 1997) and best practice weighting factors as given in Appendix D. Carbon intensity factors by fuels used are presented in Appendix F.

However, given the priority allocation of natural gas to fertilizer production, natural gas may not be sufficiently available to the iron and steel industry in the short or even long term. Hence, the petroleum based case assumes the use of petroleum products instead of gas for best practice iron and steel production. Information on the fuels employed in different best practice production steps is provided by Worrell et al., 1993. Carbon emissions per unit of fuel used as well as the carbon intensity per unit of energy of different fuels specific to India are presented in Appendix F. Complete conversion of carbon to CO_2 has been assumed.

The table shows that carbon dioxide emissions amounted to about 3.3 tonne of CO_2 per tonne of crude steel in 1993 and 1994. In 1995, emissions were slightly lower at 3.1 t CO_2 per tonne of crude steel. The gas based case reveals a savings potential for CO_2 emissions of 41% to 48% for the three years under consideration. Best practice CO_2 emissions amount to only about 1.7 to 1.8 tonnes of CO_2 per tonne of crude steel. They vary from year to year due to structural changes in the sector. Between 1993 and 1995, best practice CO_2 emissions show an increasing trend leading to reduced savings potentials. The petroleum based case shows savings potentials in the range of 38% to 45%, slightly lower than in the gas based case. This is due to the higher CO_2 intensity of petroleum products.

Table 4.5: Total Carbon Dioxide Emissions

	Base Case	Frozen Efficiency (FE)			Best Practice Gas Based			Best Practice Petroleum Based		
	1993	2001	2005	2010	2001	2005	2010	2001	2005	2010
tCO_2/tcs	3.30	3.30	3.30	3.30	1.73	1.73	1.73	1.81	1.81	1.81
Crude Steel (Mt)	18.16	29.12	36.15	47.51	29.12	36.15	47.51	29.12	36.15	47.51
Total CO_2 (Mt)	59.94	96.12	119.36	156.84	50.23	62.37	81.96	52.64	65.36	85.89

The analysis shows that assuming 1995 production patterns overall CO_2 emissions from the iron and steel sector could be reduced from currently 65 million tonnes to a lower end of about 38 million tonnes. Assuming 1993 structure (as in the section on energy efficiency), the scenario forecast (Table 4.5) reveals that best practice gas based technology would lead to net reductions in CO_2 emissions until around 2005. For the petroleum based case net reductions could be achieved until a slightly earlier point of time. Thereafter, due to increases in production activity CO_2 emissions would exceed 1993 base year emissions. While in the frozen efficiency scenario emissions in 2010 will be 2.6 fold the 1993 base year emissions, gas based best practice emissions will surmount 1993 base year emissions by only 37% (43% for the petroleum case, respectively). As presented above, the frozen efficiency scenario will result at emissions almost double the emissions of the best practice scenario. The findings support that energy efficiency as well as energy conservation measures are highly effective in reducing domestic as well as global environmental impacts.

5. Summary and Conclusions

In this paper, we investigate India's iron and steel sector from various angles. We develop economic as well as engineering indicators for productivity growth, technical change and energy consumption that allow us to investigate savings potentials in specific energy use as well as carbon dioxide emissions. We discuss our findings within a broader context of structural and policy changes in the sector. The economic analysis shows that productivity has been decreasing over time. The decline in productivity was caused largely by government protection regarding prices and distribution of steel and by inefficiencies in integrated steel plants that were reserved to the public sector. With liberalization of the iron and steel industry productivity increased substantially to positive growth rates.

We further introduce cost effective and low cost potentials for reducing energy consumption as well as carbon emissions. In comparing Indian energy consumption to best practice energy consumption we show that energy savings of about 50% 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 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 carbon emissions on a long run basis, substantial additional 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. 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

Steel Historical Estimates

Author	Method/Measure	Source of Data	Period	Growth Rate
Ahluwalia (1991)	TFPG : TL	ASI	1960-85	-1.6
	PP: Capital			-2.8
	PP: Labor			0.1
	Cap/Lab Ratio			5.1
CSO (1981)	TFPG: Kendrick		1960-77	0.07
	PP: Capital			-0.81
	PP: Labor			0.89
	Cap/Lab Ratio			1.7
	TFPG: Kendrick		1960-71	-0.74
	PP: Capital			-2.74
	PP: Labor			1.48
	Cap/Lab Ratio			4.22
	TFPG: Kendrick		1969-77	1.29
	PP: Capital			2.07
	PP: Labor			0.0
	Cap/Lab Ratio			-2.07
Goldar (1986)	TFPG: Kendrick	ASI	1960-70	-1.66
	PP: Capital			-3.23
	PP: Labor			0.96
	Cap/Lab Ratio			5.28
Kumari (1993)	TFPG: Kendrick	PE Survey	1971-87	-1.55
	TFPG: Solow			-1.33
	TFPG: Divisia			-1.2
	PP: Capital			-2.54
	PP: Labor			-0.74
	Cap/Lab Ratio			1.8
	CD Prod. Function			3.86
	CES Prod. Function			4.2
Mehta (1980)	TFPG: Solow	CMI/ASI	1953-64	-6.3
	TFPG: Kendrick			-22.9
	PP: Capital			-22.8
	PP: Labor			-5.2
	Cap/Lab Ratio			16.8
	CD Prod. Function			8.8
Pradhan (1998)	TPG: Translog		1963-92	-2.09*
			1963-71	-4*
			1982-81	1.49*
			1982-92	-2.4*
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 B

Steel Production-Productwise **(million tonnes)**

Year	Pig Iron (Hot Metal)	Steel Ingots* (Crude Steel)	Finished Steel	Steel castings ('000 t)
1970-71	6.99	6.14	4.64	62
1975-76	8.48	8.28	5.75	62
1976-77	10.02	8.73	6.80	63
1977-78	9.53	9.81	6.97	70
1978-79	9.52	10.13	7.65	75
1979-80	8.58	9.89	6.90	73
1980-81	9.55	10.33	6.82	71
1981-82	9.69	10.95	7.75	83
1982-83	9.58	11.03	8.05	88
1983-84	9.19	10.48	6.14	89
1984-85	9.24	10.81	7.78	85
1985-86	10.06	12.15	9.49	93
1986-87	10.44	12.20	9.55	104
1987-88	10.87	12.87	11.68	170
1988-89	11.88	13.96	12.84	211
1989-90	11.96	13.72	13.00	239
1990-91	12.15		13.53	262
1991-92	14.35	12.63	14.33	393.3
1992-93	15	13.25	15.2	358.1
1993-94	15.7	13.9	15.1	359.4
1994-95	17.1	14.7	17.8	383.2
1995-96	16.2	15.6	21.4	371.1
Source: Government of India, Economic Survey (1985-86, 1993-94, 1996-97)				

*The figures of steel ingots include the production of mini-steel plants.

Appendix C

Using data from 1970/71 to 1995/96, the following simple regression relationships between crude steel production and a) GDP_{total}, b) $GDP_{industry}$ and c) GDP contributed by the iron and steel sector have been obtained:

a) $CS = 7.65E\text{-}05 * GDP_{total}$ $R^2 = 0.97$
(83.61)

b) $CS = 2.32 + 2.37E\text{-}04 * GDP_{industry}$ $R^2 = 0.96$
(5.68) (25.33)

c) $CS = 3.81 + 5.51E\text{-}05 * GDP_{iron\&steel}$ $R^2 = 0.81$
(4.00) (8.96)

where CS indicates crude steel production. Crude steel is measured in Mt while both GDP_{total} and $GDP_{industry}$ are measured in 1980-81 and $GDP_{iron\&steel}$ (1973-93) in 1981-82 const. Rs. crore (Government of India, Economic Survey, 1997 and ASI, various years). T-statistics are given in parenthesis. All estimates are statistically significant.

Appendix D

Best Practice Weighting Factors for Various Products

Process	Fuel GJ/t	Electricity GJ/t	Final Energy Use GJ/t
Blast Furnace (total)[1]	15.19	0.26	15.45
Sinter Plant	1.37	0.23	1.60
Pellet Plant	0.51	0.11	0.62
Blast Furnace	13.31	-0.09	13.22
DRI[2]	10.50	0.40	10.9
BOF-slab[3]	0.57	0.12	-0.45
EAF-slab[3]	0.79	1.52	2.31
Hot Rolling[3]	1.82	0.37	2.19
Cold Rolling[3]	1.1	0.53	1.63

[1]The 'benchmark SEC' is based on the 1988 performance at Hoogovens (Worrell et al., 1993).
[2]Taken from Midrex (1993).
[3]As provided by Worrell et al. (1997).

Appendix E

List of Facilities and Practices for Energy Management in an Integrated Iron and Steel Plant

Sr. No.	Energy Saving Category	Nature of Energy Saving Technique
Coke Ovens and By-product Plant		
a)	Improved material output	Charging of preheated coal, dried coal, briquetted coal.
b)	Improved efficiency of energy utilization	Improved operational control (excess air ratio) coking time, temperatures in combustion chambers, steam driven exhauster, automatic combustion control, control of operating schedule, programmed heating, thinner walls.
c)	Energy loss prevention	Automatic ignition of CO gas flare.
d)	Recycling and recovery of waste energy	CO gas sensible heat recovery, recovery of coke sensible heat ammonia incinerator waste heat boiler.
Sinter Plant		
a)	Improved material input	Control of particle size distribution, control of raw material properties.
b)	Improved efficiency of energy utilization	Increased bed depth, combustion control of ignition furnace, two layer charging.
c)	Energy loss prevention	Prevention of air leakage from wind box.
d)	Recycling and recovery of waste energy	Sinter cooler waste heat preheating of ignition furnace combustion air.
e)	Power saving	Rotative speed control and high efficiency impeller for main exhaust gas fan.
Blast Furnace		
a)	Improved material input	Lowering of slag volume, improved sinter quality
b)	Improved efficiency of energy utilization	Improved charge distribution, optimum blast temperature, blast humidity
c)	Energy loss prevention	Automatic ignition of BF gas flare, recovery of BF gas bled during charges. insulation of cold blast main and tuyers.

List of Facilities and Practices for Energy Management in an Integrated Iron and Steel Plant (contd.)

d)	Improved process step linkage or step elimination	Warm charging of coke and sinter.
e)	Recycling and recovery of waste energy	Top gas recovery turbine, evaporative stove cooling, BF gas sensible heat recovery, blast furnace slag sensible heat recovery, hot stove exhaust gas sensible heat recovery.
f)	Power saving	Rotative speed control of dust collector fans.
BOF Steel-making		
a)	Improved material input	Hot metal of improved quality of low sulfur and appropriate silicon.
b)	Improved efficiency of energy utilization	Optimized blowing practice, programmed control of ladle preheating, combined blowing.
c)	Energy loss prevention	Ladle preheating, automatic ignition of BOF gas flare.
d)	Improved process step linkage or step elimination	Higher hot metal temperatures at BOF by shortening ladle cycle time installing lid on transfer ladle.
e)	Recycling and recovery of waste energy	Recovery of BOF gas sensible and chemical heat, recovery of slag sensible heat, recovery of continuously cast sensible heat.
Source: Mishra (1998).		

Energy Saving Investment Efficiency

A. Automatic Ignition of Coke Oven Gas Flare	
Units Equipped	: 4 Coke Oven Batteries
Investment	: Rs. 2.0 Crores
Energy Recovered	: 3 Mcal / tcs
Fuel Saved / Annum	: 1962 tonnes of Furnace Oil
Savings	: Rs. 1.37 Crores
Pay Back Period	: 1.3 Years
B. Top Gas Recovery Turbines	
Units Equipped	: 2 Blast Furnaces
Investment	: Rs. 100.0 Crores
Energy Recovered	: 70 kWh / tcs
Electricity Saved / Annum	: 387 Million units
Savings	: Rs. 115.0 Crores
Pay Back Period	: 1.00 Years
C. Hot Stove Waste Heat Recovery	
Units Equipped	: 2 Blast Furnaces
Investment	: Rs. 15.0 Crores
Energy Recovered	: 15 Mcal / tcs
Fuel Saved / Annum	: 9800 tonnes of Furnace Oil
Savings	: Rs. 6.86 Crores
Pay Back Period	: 3.5 Years
D. BOF Gas Recovery	
Units Equipped	: 3 BOF Vessels
Investment	: Rs. 300 Crores
Energy Recovered	: 200 Mcal / tcs
Fuel Saved / Annum	: 130000 tonnes of Furnace Oil
Savings	: Rs. 91.0 Crores
Pay Back Period	: 5.7 Years

Energy Saving Investment Efficiency **(contd.)**

E. Double Insulation of Skids	
Units Equipped	: 3 Slab Reheating Furnaces
Investment	: Rs. 5.0 Crores
Energy Recovered	: 10 Mcal / tcs
Fuel Saved / Annum	: 6540 tonnes of Furnace Oil
Savings	: Rs. 4.55 Crores
Pay Back Period	: 1.4 Years
F. Coke Dry Quenching Unit	
Units Equipped	: 4 Coke Oven Batteries
Investment	: Rs. 550 Crores
Energy Recovered	: 150 kWh / tcs
Electricity Recovered/ Annum	: 833 Million units
Savings	: Rs. 250 Crores
Pay Back Period	: 3.4 Years
G. Coke Oven Automatic Combustion Control	
Units Equipped	: 4 Coke Oven Batteries
Investment	: Rs. 18.0 Crores
Energy Recovered	: 12 Mcal / tcs
Fuel (Coal) Saved / Annum	: 17250 tonnes of Coal
Savings	: Rs. 5.2 Crores
Pay Back Period	: 6.0 Years
H. Sinter Cooler Sensible Heat	
Units Equipped	:2 Sinter Coolers
Investment	: Rs. 100.0 Crores
Energy Recovered	: 40 Mcal / tcs
Fuel Saved / Annum	: 26250 tonnes of Furnace Oil
Savings	: Rs. 18.40 Crores
Pay Back Period	: 10 Years
I. Bled BF Gas Recovery	
Units Equipped	: 4 Coke Oven Batteries
Investment	: Rs. 14.0 Crores
Energy Recovered	: 10 Mcal / tcs
Fuel Saved / Annum	: 6540 tonnes of Furnace Oil
Savings	: Rs. 4.50 Crores
Pay Back Period	: 5.5 Years
J. BOF Sensible Heat	
Units Equipped	: 3 BOF Vessels
Investment	: Rs 100.0 Crores
Energy Recovered	: 30 Mcal / tcs
Fuel Saved / Annum	: 20,000 tonnes of Furnace Oil
Savings	: Rs. 14.0 Crores
Pay Back Period	: 13 Years
Source: Mishra (1998).	

Appendix F

Carbon Emissions and Intensity of Fuels Used in the Steel Manufacturing Processes

Fuel	Units	Carbon emissions (t/unit)	CO_2 Intensity (tCO_2/GJ)
Coking coal	tonne	0.58	0.074
Non-coking coal (reductant)	tonne	0.56	0.092
Boiler Coal	tonne	0.43	0.095
Coke	tonne	0.75	0.094
Petroleum Products	tonne	0.85	0.074
Natural Gas	1000 nm^3	0.5	0.053
Electricity*	1000 kWh	0.27	0.271
Source: Das and Kandpal (1997).			

*Assuming a conversion efficiency of 35% in a coal fired thermal power plant.