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India's Pulp and Paper Industry: Productivity and Energy Efficiency

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Environmental Energy Technologies Division

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Abstract

Historical estimates of productivity growth in India's pulp and paper 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 statistical and econometric estimates of productivity growth for this sector. Our results show that productivity declined over the observed period from 1973-74 to 1993-94 by 1.1% p.a. Using a translog specification the econometric analysis reveals that technical progress in India's pulp and paper 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 protection afforded by high tariffs on imported paper products and other policies, which allowed inefficient, small plants to enter the market and flourish. Will these trends continue into the future, particularly where energy use is concerned? We examine the current changes in structure and energy efficiency undergoing in the sector. Our analysis shows that with liberalization of the sector, and tighter environmental controls, the industry is moving towards higher efficiency and productivity. However, the analysis also shows as these improvements are being hampered by significant financial and other barriers the industry might have a long way to go.

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1. Introduction

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

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

In this paper we contribute to the discussion on productivity growth and the role of technological change. We introduce the pulp and paper industry in more detail taking into account industry specific aspects such as structural composition, production, technologies, energy consumption within processes, sector specific policies etc. This following we derive both statistical and econometric estimates of productivity growth for the fertilizer sector over time. For the statistical analysis we develop the Kendrick and Solow indices while for the econometric analysis a translog cost function approach using both cross-state and national time series data is employed. The results are then interpreted within a broader context of structural and policy changes in the sector as well as other sector specific aspects.

Future energy use depends 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 pulp and paper industry structure. It compares world best technologies to Indian technologies and identify potentials and barriers to the adoption of such efficiency improvements. We conclude the report in highlighting the energy efficiency and productivity improvements that could be achieved by employing more efficient technologies.

2. Pulp and Paper Industry

2.1 The Pulp and Paper Industry in Context

In the course of this study, six industries in India have been identified as energy-intensive industries: aluminum, cement, fertilizer, iron and steel, glass, and paper. Together they account for 16.8% of manufacturing value of output (VO) and consume 38.8% of all fuels consumed in the manufacturing sector (Table 2.1) [1]. The pulp and paper sector holds a considerable share within these energy intensive industries. In 1993, it accounted for 11% of value of output within the six industries and for 1.9% in the manufacturing sector.

Table 2.1: Economic Indicators for the Pulp and Paper Industry

	Unit	Pulp and Paper	Aggregate of Six Energy Intensive Industries	Aggregate Manufacturing
Growth in Value of Output[1]				
Nominal				
1973-1993	% p.a.	15.1	16.4	15.1
1973-1982	% p.a.	14.3	19.6	16.2
1982-1990	% p.a.	17.5	14.7	14.3
1990-1993	% p.a.	11.0	11.5	14.0
Real				
1973-1993	% p.a.	5.3	7.9	7.4
1973-1982	% p.a.	4.7	9.4	8.5
1982-1990	% p.a.	8.5	9.0	7.2
1990-1993	% p.a.	-1.9	0.4	4.4
In 1993-94:				
VO Share in Aggr. Manufacturing (nominal)	Sector VO/ Manuf. VO	1.9%	16.8%	100%
Sector Fuel Share in Aggr. Manuf. (nominal)	Sector Fuel/ Manuf. Fuel	4.2%	38.8%	100%
Share of Fuel Costs in Value of Output (nominal)	Sector Fuel/ Sector VO	15.2%	15.8%	6.8%
Source: Government of India, ASI: Summary Results for the Factory Sector, various years.				

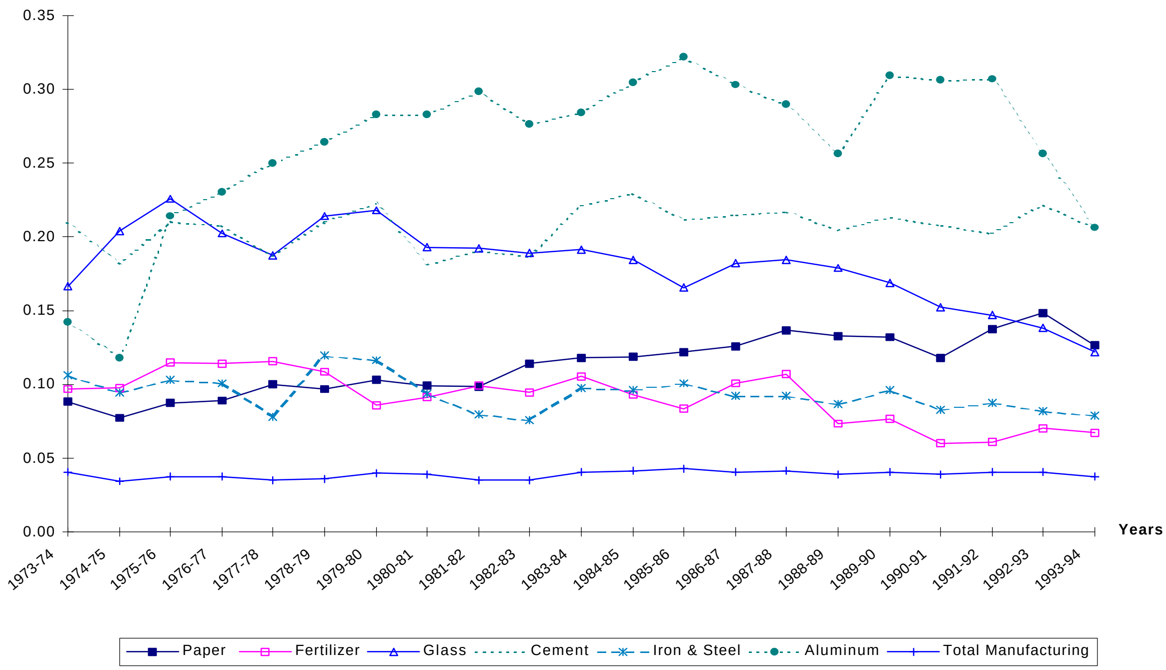
[1] calculated as exponential annual growth.

Production in the pulp and paper sector has been increasing over the last 20 years. As seen in Table 2.1 major increases in real VO (8.5%) took place between 1982 and 1990, while growth was significantly lower before that period (1973-82) at 4.7% and declining thereafter (1990-93) at –1.9%. Compared to the aggregate of the six energy intensive industries growth in the paper sector was significantly lower between 1973 and 1982, amounted to a little less than the average in the period of 1982 to 1990 and fell short of the average again between 1990-1993. The ups and downs led to an overall positive

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

growth in output between 1973 and 1993 of 5.3% which is well below the average of 7.9% of the six energy intensive industries.

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



In 1993-94, the pulp and paper sector accounts for 4.2% of total fuels consumed in the manufacturing sector. Within the group of energy intensive industries, the share of fuels consumed per unit of output (VO) is about average with 15.2%. However, compared to the average manufacturing fuel consumption per unit of output the paper sector consumes twice the amount of fuels per unit of output (VO). Figure 2.1 displays the energy intensity of the pulp and paper sector in real values. The 'real-value' indicator reflects the changes in physical energy intensity over time and gives a comparison to other sectors. Pulp and paper production was least energy intensive in the early years. However, over time energy intensity increased steadily shifting the pulp and paper sector to the third most energy intensive industry in 1993.

2.2 Pulp and Paper Process

The pulp and paper industry converts fibrous raw materials into pulp, paper and paperboard. In a first step raw materials are processed into pulp and in a second step paper and paper products are produced out of this pulp. Different plant categories exist depending on whether they only produce pulp (pulp mills) for further processing or only paper out of purchased pulp and/or recycled waste paper (paper mills). The third category, the integrated pulp and paper mills, combines the two processes and is most common in the paper industry.

The five principal steps in pulp and paper production are wood preparation, pulping, bleaching, chemical recovery, and papermaking. The following step by step description is adapted from the World Energy Council, 1995.

2.2.1 Wood Preparation

Wood preparation involves breaking wood down into small pieces suitable for subsequent pulping operations. Major wood preparation processes include debarking and chipping. This process requires little energy.

2.2.2 Pulping

Wood is ground and pulped to separate the fibers from each other and to suspend the fibers in water. Pulping breaks apart the wood fibers and cleans them of unwanted residues. The ratio of wood to other materials used for pulp depends on the resources available. The remaining fiber is provided by recycled materials or by non-wood plant sources.

Pulping can be performed using chemical, mechanical, or combined chemical-mechanical techniques. In chemical pulping wood chips are cooked in an aqueous solution at high temperature and pressure. Chemical processes dissolve most of the glue that holds the fibers together (lignin) while leaving the cellulose fibers relatively undamaged. This process results in high quality paper with a yield of only 40%-60% of the weight of the dry wood. The Kraft process, which is the most common, uses a sodium hydroxide and sodium sulfide solution. The sulfite process uses a mixture of sulfurous acid and bisulfite iron (typically from sodium sulfite).

The most common mechanical pulping technique involves separating the cellulose fibers by pressing logs against wet grindstones or by passing wood chips between counter revolving grooved metal disks (refiners). Lignins and other residues are not removed. This results in a higher yield, but there is more damage to the fibers. In addition, lignin will degrade in time. The lower quality fiber limits the use of this process to less expensive grades of paper, such as newsprint.

Combined chemical and mechanical pulping can produce varying grades of paper depending on the particular process used. These processes include thermo-mechanical, chemical thermo-mechanical, and semi-chemical.

Large Indian mills that are predominantly based on forest raw materials use the Kraft process. Agro-based mills use a soda process while newsprint mills use mechanical, chemical, chemi-mechanical and chemi-thermormechanical (CTMP) processes. (Mohanty, 1997)

2.2.3 Bleaching

Bleaching whitens pulps for the manufacture of writing, printing, and decorative papers. The process alters or removes the lignin attached to the wood fiber. Chemical pulps are bleached through the use of alternating treatments of oxidizing agents and alkali solutions. The Kraft process produces a darker pulp which requires more bleaching. Mechanical pulps are treated with hydrogen peroxide or sodium hydrosulfite to reduce the light absorption of the lignin rather than remove it.

2.2.4 Chemical Recovery

Chemical recovery regenerates the spent chemicals used in Kraft chemical pulping. Chemical pulping produces a waste stream of inorganic chemicals and wood residues known as black liquor. The black liquor is concentrated in evaporators and then incinerated in recovery furnaces, many of which are connected to steam turbine cogeneration systems. The wood residues provide the fuel and the chemicals are separated as smelt which is then treated to produce sodium hydroxide. Sodium sulfide is also recovered.

2.2.5 Papermaking

Papermaking consists of preparation, forming, pressing and drying; preparation and drying are the most energy intensive processes. During preparation, the pulp is made more flexible through beating, a mechanical pounding and squeezing process. Pigments, dyes, filler materials, and sizing materials are added at this stage. Forming involves spreading the pulp on a screen. The water is removed by pressing and the paper is left to dry. In one of the most common papermaking processes, the paper is pressed, drained and dried in a continuous process. In another, a pulp matt is formed in layers with water removal and treating occurring between deposits.

2.3 Pulp and Paper Production in India

Although per capita paper consumption in India is very low compared to other countries the paper industry holds a considerable share in manufacturing production. Today more than 380 small and big paper mills produce a variety of different paper, paperboard as well as newsprint products. Cultural paper constitutes the biggest share in production with 41% (in 1991), followed by kraftpaper with a share of 27%, paperboard with 17%, newsprint with 12% and specialty paper at 3% (Sharma et al., 1998). Installed production capacity increased substantially from 0.77 million tonnes[2] in 1970-71 to 3.95 million tonnes in 1994-95. Production, however, has not increased accordingly. While in 1970-71 production ran at almost full capacity, in 1994-95, only 2.51 million tonnes of paper and paper board were produced. Capacity utilization had decreased from 99% in 1970-71 to a low of 60% in 1992-93 and slightly increased again to 64% in 1994-95.

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

Table 2.2: Paper: Number of Paper Mills, Production and Capacity (million tonnes)

Year	No. of Mills	Capacity	Production	Capacity Utilization
1970-71	57	0.77	0.76	99%
1980-81	135	1.65	1.11	67%
1990-91	325	3.30	2.06	62%
1991-92	326	3.36	2.11	63%
1992-93	340	3.55	2.13	60%
1993-94	372	3.79	2.33	61%
1994-95	380	3.95	2.51	64%
Source: CMIE (1996); TERI (1996).				

India has a manifold variety of newspapers. Newsprint production has increased considerably since 1980-81 (Table 2.3). In 1994-95 it was at over 0.3 million tonnes. Installed capacity, however, would have allowed for more than 0.5 million tonnes newsprint production. Capacity utilization was low in the 1980s, increased significantly in the early 1990s and was lower again at 68% in 1993-94.

Table 2.3: Newsprint: Production and Capacity (thousand tonnes)

Year	Capacity	Production	Capacity Utilization
1980-81	75	48	64%
1990-91	313	280	90%
1991-92	313	295	94%
1992-93	373	312	84%
1993-94	535	361	68%
Source: CMIE (1996).			

Size, type and quality of the paper producing units are very diverse. As of 1995, more than 50% of paper and paper board products were produced in only 38 paper mills. The average size of a paper mill in India was 10,400 tonnes per year (tpa), compared with 85,000 tpa in Asia and about 300,000 tpa in Europe and North America. About two thirds of India's paper mills have a capacity of less than 18,000 tpa (Meadows, 1997). Large mills are defined as mills with an installed capacity exceeding 20,000 tpa. Medium size mills have a capacity between 10,000 tpa and 20,000 tpa while small mills are defined as mills with a capacity of less than 10,000 tpa. According to this definition, only 48 large mills holding a share of 52% of total capacity were counted in India in 1990. The range of size within this category varied considerably, between 20,000 tpa and more than 100,000 tpa. Large mills account for nearly 90% of the cultural paper production.

Small and medium size paper mills became important when due to a severe paper shortage in the early 1970s the government promoted the immediate establishment of small, readily available paper units. This following cheap second hand technologies were imported that could be set up in any part of the country. As a result of the paper shortage and overall government pricing policy the small and medium sector with more than 300 paper mills accounted for almost 50% of installed capacity and production in 1992. They produce primarily low quality paper such as kraftpaper and paperboards from recycled paper and various agro-fibers. (Meadows, 1997; Sharma et al., 1998)

Yet, the small units suffer from high production costs, uneconomic operation, low quality and negative impacts on the environment. About 150 small mills are currently closed or sitting idle (Meadows, 1997). Already old when imported the units have further degraded since, which has led to the current situation of low productivity, low efficiency, excessive resource consumption, obsolete technologies, capacity underutilization and low scale of operation. International competition and the high quality and low production costs of imported paper will also force many small mills to close. Furthermore, most small and medium size pulp and paper mills cannot economically provide chemical recovery and pollution control systems. Therefore, they are highly polluting industries contributing substantially to the overall level of emissions and environmental problems. (Datt and Sundharam, 1998)

With the advent of economic liberalization and stricter environmental regulations the promotion of larger more efficient paper mills has been initiated. Presently, large paper mills are more efficient, using better and more modern technologies and appropriating economies of scale. Additionally, they provide chemical recovery facilities which reduce both emissions and external energy requirements. However, the large paper mills also face severe basic problems such as high production costs, raw material constraints and low productivity. Overall performance has been best in medium size firms with regards to average profitability (Sharma et al., 1998).

Demand for paper and paper products has continuously been increasing over time. Consumption of paper and paper board equaled 1.2 million tonnes in 1980-81 and increased to 2.6 million tonnes in 1994-95. This trend is expected to be maintained in the future. Per capita consumption of paper, in 1995, was one of the lowest in the world. Nevertheless, production today as in the past could not meet demand. Imports accounted for about 7% of consumption in 1980-81. With the increase of capacity through small mostly agro-based paper mills in the early 1980s, imports of paper and paper board decreased to only 2% of consumption in 1985 and to less than 1% in 1990-91. In 1994-95, however, they reached up again to over 10%. Shortage of newsprint has been even higher both in the past and today. On average, about 0.2 million tonnes of newsprint (about 40% of consumption) had to be imported in the last few years.

2.3.1 Raw Material Constraint

Regarding the use of raw materials in India one can categorize three types of mills: forest based mills, agro waste/residue based mills and recycled fibre based mills. In 1992, forest based raw materials account for about 49% of total raw material inputs for paper, paper board and newsprint production, while the share of agricultural residues and wastepaper amount to 29% and 22% respectively (Sharma et al., 1998). The consumption share of forest based materials has been declining over time and is expected to further decrease to 47% by 2000. The share of agricultural residues shows a steadily increasing trend from 1980 to today and is expected to further rise in the future. At the same time wastepaper use which has risen from 13% in 1985 will approximately hold its share. (Srivastava, 1998)

The small paper mills set up in the early seventies almost exclusively use agro waste/residues as raw materials for paper production. Large mills, so far, have mainly been based on forest material for paper production. This includes bamboo, hardwood and eucalyptus. While agro waste/residues such as rice straw, wheat straw and bagasse are relatively short cycled regenerative and abundant, the availability of forest based raw material is rather limited.

With the implementation of central and state government policy towards forests protection and afforestration, pulp and paper mills now have to take responsibility for the reduction of forest material consumption and afforestration efforts. The government is encouraging the industry to create plantations on degraded forest and waste land (dedicated forest program). The overall constraint of raw materials will force the paper industry in future to rely more and more on imports of pulp or final paper products. To overcome the raw material shortage the government has liberalized the import of raw materials and given excise concessions for the use of non conventional raw materials.

2.3.2 Energy Use

Pulp and paper production is highly energy intensive with 75-85% of the energy requirement being used as process heat and 15-25% as electrical power. The combination of these two energy requirements qualifies paper production for the use of cogeneration (low pressure steam for process heat and high pressure steam for electricity generation). Specific energy consumption in a typical Indian bleached Kraft mill in 1987 is shown in Table 2.4. More than forty percent of the electricity and more than thirty percent of the fuels consumed is produced or recovered on-site. Of the total final energy used, fuels from internal sources comprise only 33% in India compared to 60-70% in developed countries (Mohanty, 1997; Rao, 1989).

Table 2.4: Specific Energy Consumption in a Typical Indian Integrated Bleached Kraft Mill (1987)

	Fuel GJ/t of paper	Electricity GJ/t of paper	Electricity kWh/t of paper	Final Energy GJ/t of paper
Purchased	39.23	3.31	918	42.54
Internally generated	19.18	2.37	658	21.55
Sum	**58.41**	**5.67**	**1576**	**64.08**
Source: BICP (1987).				

Despite rising energy prices, energy consumption in the Indian paper industry has increased over time. This is mainly due to declining rates of capacity utilization in running plants, increases in the production of specialty papers, shortages of paper and coal and inadequate and unsuitable supply of raw materials. (Rao, 1989)

Table 2.5: Energy Consumption in Indian Paper Mills

Section/Equipment	Steam (t/t of paper)	Fuel* (GJ/t of paper)	Electricity (kWh/t of paper)	Final Energy (GJ/t of paper)
Chipper			112-128	0.4-0.5
Digester	2.7-3.9	12.5-18.0	58-62	12.7-18.2
Evaporator	2.5-4.0	11.5-185		11.5-18.5
Washing & Screening			145-155	0.5-0.6
Bleaching	0.35-0.4	1.6-1.8	88-92	1.9-2.2
Soda Recovery	0.5-1.1	2.3-5.1	170-190	2.9-5.8
Stock Preparation			275-286	0.99-1.03
Paper Machine	3.0-4.0	13.8-18.5	465-475	15.5-20.2
Deaerator	0.8-1.2	3.7-5.5		3.7-5.5
Utilities and Others			248-252	0.89-0.91
Total	**10-16**	**46.2-73.8**	**1500-1700**	**51.6-80.0**
Source: Srivastava (1998); TERI (1996), and Mohanty (1997).				

*Fuel used for steam production - assuming an enthalpy value for steam of 3.0MJ/kg and 65% boiler efficiency (Blok, 1992).

In general, the production process consists of 5 stages: raw material preparation, pulping, bleaching, chemical recovery and paper-making. Most of the energy is used in form of heat within the pulping process (digester, evaporator and washing) when raw materials have to be cooked and mechanically or chemically treated for further use in the production chain. In the United States, for example, the pulping process consumes about a quarter of all primary energy required for paper production (World Energy Council, 1995). Furthermore, paper making requires considerable amounts of energy in form of both heat and electricity for forming, pressing and drying of the paper. In the United States this process consumes nearly 40% of all the energy required for the pulp and paper sector. (World Energy Council, 1995) Table 2.5 displays in detail the energy consumption in Indian paper industries split up by section or equipment.

Energy consumption is also highly dependent on the type of raw material used in the production process. Energy consumption for pulping and digesting, for example, is lower if wastepaper is used instead of wood chips or agricultural residue. In general, the use of wastepaper requires about 2.5 time less energy than a similar production process based on other inputs mainly because of less intensive pulping needs for wastepaper (Sharma et al., 1998).

2.3.3 Environmental Impact

The pulp and paper industry is a chemical process industry with major impact on the environment. The potential pollutants from a pulp and paper mill can be classified into four categories: (1) liquid effluents, (2) air pollutants, (3) solid wastes and (4) noise pollution (Mohanty, 1997; Srivastava, 1998).

The environmental problems faced by large and small paper mills are entirely different. Pollution control is more difficult for small and medium size agro-based units. Chemical recovery in these units is not economically viable and therefore black liquor and lime sludge are not being burned for heat recovery. It is estimated that a 30 tpd small paper mill can be almost three times as polluting as an integrated paper mill of 200 tpd. (Srivastava, 1998)

For the same reason as wastepaper production requires substantially less energy than other processes its environmental impact is also much lower. As shown in Sharma et al. (1998) water pollution in the form of wastewater is up to 90% lower compared to wood and agro-based production. Solid waste from wastepaper production is shown to amount to only a tenth of that from agro-based production. The type and quantities of solid waste generated differ considerably across mill types.

2.4 Policy

India's pulp and paper sector has been protected by government policy for more than three decades. Controls on production, distribution and prices impeded the growth of the industry substantially. During the paper shortage in the 1970s and further on in the 1980s the government actively supported the venture into the paper sector in providing financial incentives to technocrats and entrepreneurs through financial institutions (Datt and Sundharam, 1998). To protect the rising small paper mill industry and ensure their existence along with larger, more economic paper mills the government gave a variety of excise concessions and reliefs. In 1974, the Government of India enforced paper manufacturers to produce white paper and supply it at a concessional rate to the educational sector and to the governmental departments. Fiscal levies accounted to as much as 35%-40% of the selling price adding to the already high-cost based prices of paper. The government additionally established high import duties on imported paper and paperboard to reduce import dependency. Export of paper was banned during the whole period. (Sharma et al., 1998)

The Government of India reacted on the lasting stagnation and financial problems of the sector in the 1980s in removing price and distribution controls on white printing paper in 1987. This allowed the paper industry to receive profitable returns on paper products and thus provided incentives to increase capacity utilization and establish new capacity. Also, the Government of India exempted paper units from excise duty, provided they used 75% of non-conventional raw materials for production. However, this exemption was abolished again in the 1990s. The concept of broad-banding has been extended to paper products since 1985-86. This implies that firms now experience the freedom to manufacture any variety of paper within the overall limit of licensed capacity (see Datt et al., 1998, Sharma et al., 1998).

Since 1992, the government has taken further measures to improve the situation of the paper sector. They include excise rebate to small units, abolition of customs duty on the import of paper grade pulp and wood chips, removal of statutory control over production, price and distribution of white printing paper and provision of infrastructural support by increased allocation of coal and wagons. While import duty on paper in 1991-92 was as high as 140% it has since gradually been reduced from 65% to 40% and further to 20% in May 1995. Yet, customs duty on inputs and intermediates have not been brought down on a similar scale. (CMIE, 1996) Import of wood pulp for the production of newsprint and newsprint products are allowed on a more flexible scale. Moreover, obligations regarding licensing and excise duty have been alleviated. While the Monopolies and Restrictive Trade Practices Act (MRTP ACT) from 1991 abolished industrial licensing for almost all industries, the paper and newsprint industry except the bagasse based units has not been exempt yet. Reasons for continued licensing of these industries were given as: security and strategic concerns, social reasons, hazardous chemicals and environmental impacts.

Environmental regulations have been set up following increasing environmental impacts in the line with rapid industrialization as well as greater awareness of environmental protection and ecological balances. The Environmental Protection Act was implemented and a Central Pollution Control Board established to set up discharge standards that should be enforced by State Pollution Boards. The standards have become more stringent over time. Since 1989 even small paper mills have to follow discharge standards in the form of minimal standards regulating liquid, air and solid waste discharges.

Table 2.6: Overview of Policies Regarding the Pulp and Paper Industry (1973 - 1993)

Period	Policy	Specifics
1951	Industrial Development and Regulation Act	Pulp and paper sector is subject to industrial licensing system.
1956	Industrial Policy Resolution	Pulp and paper sector is subject to regulation by the state.
1970s	Support of venture into paper industry	Financial incentives to technocrats and entrepreneurs through financial institutions.
1970s	Increased concession of letters of intent and licenses	Large number of licenses and letters of intent issued to small paper mills based on unconventional raw materials and second hand machinery; excise concessions to small industries.
1974	Paper Control Order	Minimum monthly production of white paper (to 30% of total production) and other varieties of cultural paper, concessional levy on supply to educational sector and government departments, other varieties of paper remain free from price control.
1974	Levies and import duty	Fiscal levies account to 35-40% of paper selling price, high import duties on paper and paperboard to reduce import dependency.
1975	Exemption from Industrial Licensing	Special exemptions from licensing granted, e.g. to agricultural residue and waste paper based production that is not import dependent.
Until 1980s	Excise and custom duty	Excise and custom duty leviable on paper and paperboard, all sorts
1980s	Exemption from excise duty	Exemption from excise duty for units using 75% and more of non-conventional raw materials; exemptions for specific other units, also from custom duty.
Until 1983	Ban of export	Exports of writing and printing paper was banned.
After 1983	Export ceiling	Exports of paper and paper boards up to 10,000 tonnes was allowed.
1985	Broad-banding in the paper industry	Under broad-banding firms are allowed to produce any variety of paper within the overall limit of licensed capacity.
1985	Exemption from Industrial Licensing	Further liberalization of the de-licensing provision from 1975; reserve of paper products exclusively for manufacture in small scale sector.
1987	Removal of price and distribution control	Removal of price and distribution control for white paper.
1989	Environmental Protection	Discharge standards even for small paper mills.
Early 1990s	Export Restriction	Exports of paper and paper boards are limited to the order of 1000 tonnes per year, only to neighboring countries (Nepal, Bhutan).
1990s	Abolishment of exemption from excise duty	Abolishment of exemption rule for units using at least 75% of non-conventional raw materials.
1992-today	Import of newsprint, wood pulp for newsprint and pulp and waste paper.	Users of over 200 tonnes of newsprint are allowed to import one tonne of newsprint against purchases of 200 tonnes of local newsprint. First wood based newsprint producers only, later wastepaper based newsprint producers as well; customs duty on imports of wood pulp for manufacture of newsprint abolished; imports of pulp and waste paper allowed without restrictions of import licenses at modest rate of custom duty of 10%.
	Exemption from licensing	Exemption from compulsory licensing subject of local policy for units using 75% and more of non-conventional raw materials.
	Low rate of excise duty	Low rate of excise duty at 5% ad-valorem for writing, printing and uncoated craft paper based on more than 75% (by weight) on pulp made from non-conventional raw material.
	Concessional rate of excise duty	Concessional rate of excise duty for mills using more than 50% agro-residues and other non-conventional raw material.
Source: Datt et al. (1998), Ahuja (1992), Sharma et al. (1998), CMIE (1996), Srivastava (1998), BICP (1987), Rao (1998).		

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 the 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 pulp and paper 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 fertilizer industry are given in Appendix A. Figures 3.1 - 3.4 display both the historical as well as our own estimates graphically. The graphical presentation allows to immediately realize the large differences in the estimates obtained by researchers for various points of time. The overview draws on Mongia and Sathaye (1998a).

Figure 3.1: Estimates of Partial Productivity Growth: Capital

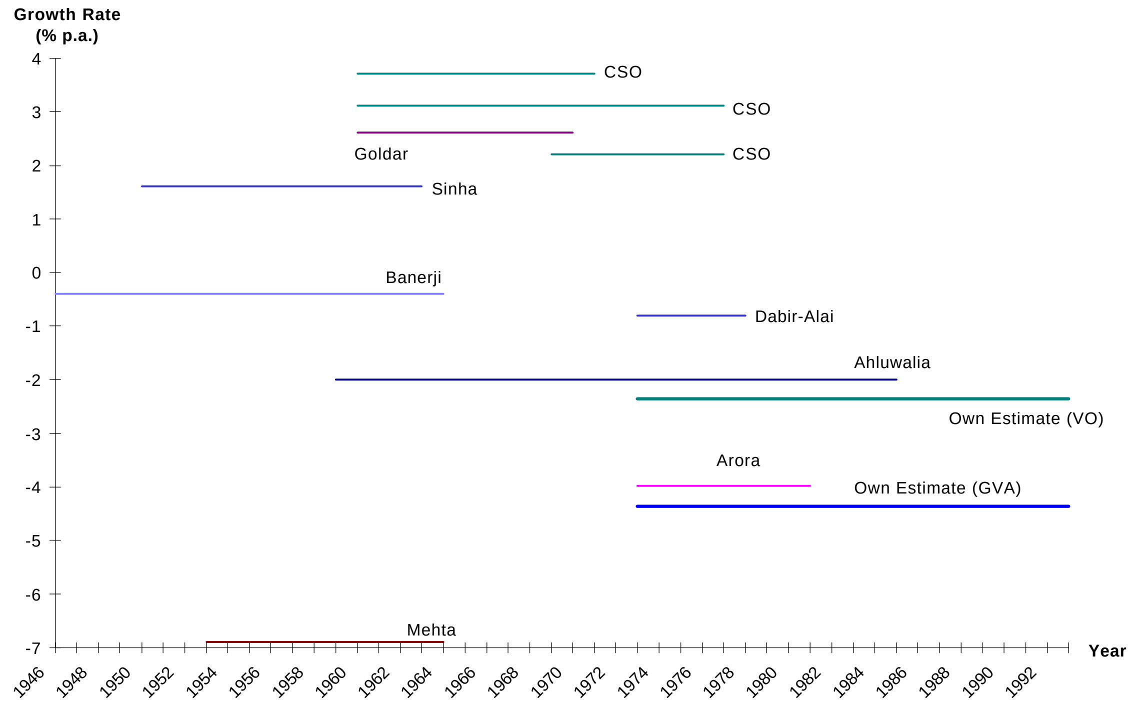


Figure 3.2: Estimates of Partial Productivity Growth: Labor

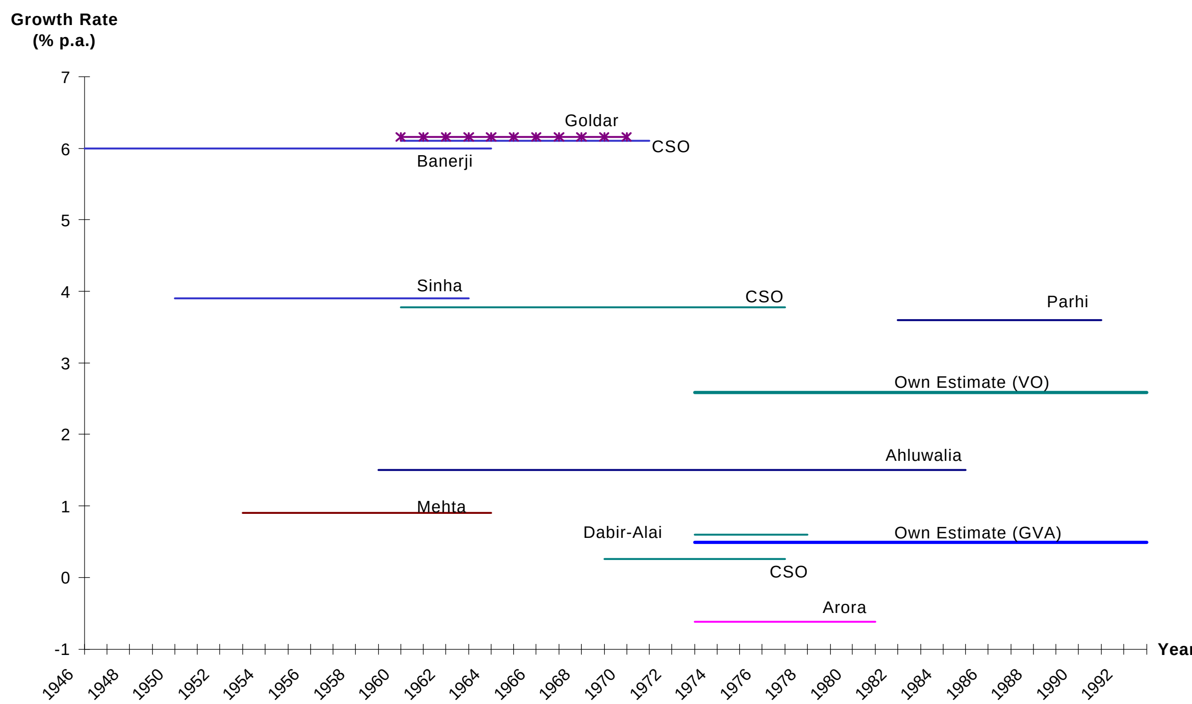


Figure 3.3: Estimates of Capital-Labor Ratio

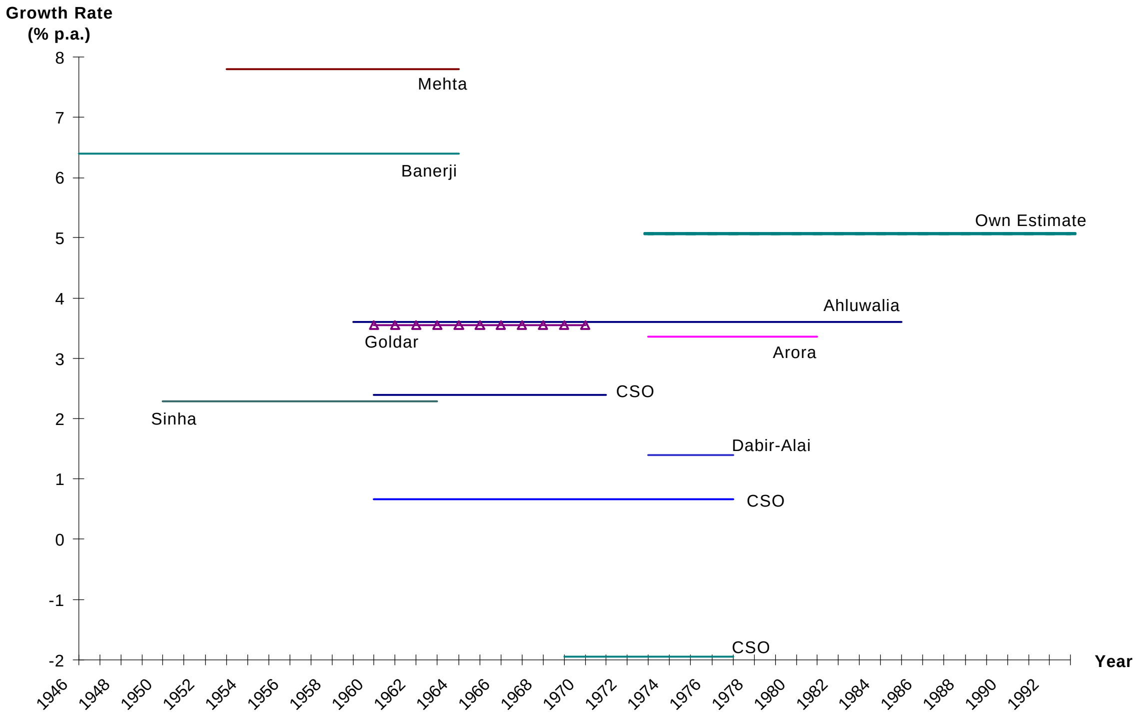
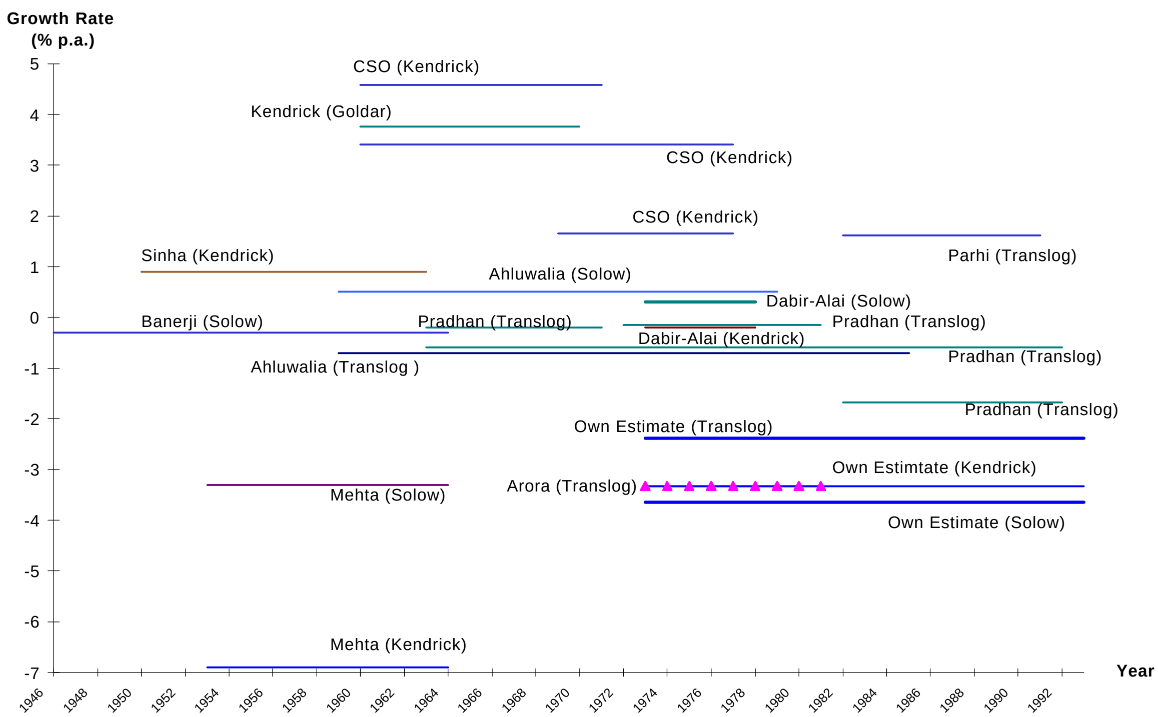


Figure 3.4: Estimates of Total Factor Productivity Growth



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

3.1.1.1 Partial Productivity Growth

Capital Productivity

Partial productivity growth estimates for capital are presented in Figure 3.1. The estimates for the different time periods range widely from positive numbers to very negative ones. The CSO study together with Goldar report highest productivity growth for the period 1960-77 and two subperiods. Earlier study periods considered by Sinh and Banerji reveal lower positive or slightly negative growth rates. All other studies report significant negative development of capital productivity over time. Most of these studies, except the study conducted by Mehta, fall in a later time period starting in 1959 and extending to 1991. Parhi (not shown in figure) concludes an outstanding productivity drop of –18.9% annually between 1982-91.

Labor Productivity

Historical estimates of labor productivity are displayed in Figure 3.2. Independent of the time period considered, most studies report positive development of labor productivity over time. The positive estimates range from low growth of 0.26% p.a. (CSO, subperiod 1969-77) to growth as high as 6.16% p.a. (Goldar, 1960-70). This is in accordance with the general belief in very significant increases of labor productivity in the past. Only Arora reports negative labor productivity development in her study covering the years 1974-82. According to her, labor productivity decreased at –0.62% p.a. during that time.

Capital-Labor Ratio

The trend of increasing labor productivity accompanied by declining capital productivity to some extent results from a process of capital deepening. Capital deepening in the Indian paper sector is confirmed for most studies by growing capital labor ratios (Figure 3.3). Both Banerji and Mehta conclude a considerable increase in the capital labor ratio over time at 6.4% and 7.8% for the time periods 1946-58 and 1953-65 respectively. Parhi (not shown in figure) even reports a capital-labor ratio increase of 22.48% p.a. between 1982-91. Other studies show more moderate increases in the ratio between 0.67% p.a. (CSO, 1960-77) and 3.6% p.a. (Ahluwalia, 1959-85). For a small subperiod, 1970-77, the CSO study reports a decline of –1.95% p.a.

Energy and Material Productivity

In addition to the investigation of capital and labor productivity Banerji considers energy and material productivity in his study (see Appendix A). He concludes that energy productivity decreased over the sample period (1946-64) at 2.5%, while material productivity increased slightly at an average rate of 0.2%.

3.1.1.2 Total Factor Productivity Growth

Total factor productivity change in the paper sector has been investigated in various studies. The studies report positive and negative development of total factor productivity depending on the time period and productivity index considered. Estimated productivity growth is highest in the CSO study for the subperiod 1960-71 at 4.58% p.a. and lowest for Mehta's study, 1953-64, -6.9% p.a.

While only few studies, mainly those estimating the Kendrick index, show a positive development, the majority of studies indicates a productivity decline over time. Particularly, the studies conducted for the last two decades, with the exception of Parhi, 1982-91, report productivity declines of –0.15% p.a. (Pradhan, 1972-81) to –3.32% p.a. (Arora, 1973-81).

3.1.2 Own Estimates

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

3.1.2.1 Partial Productivity

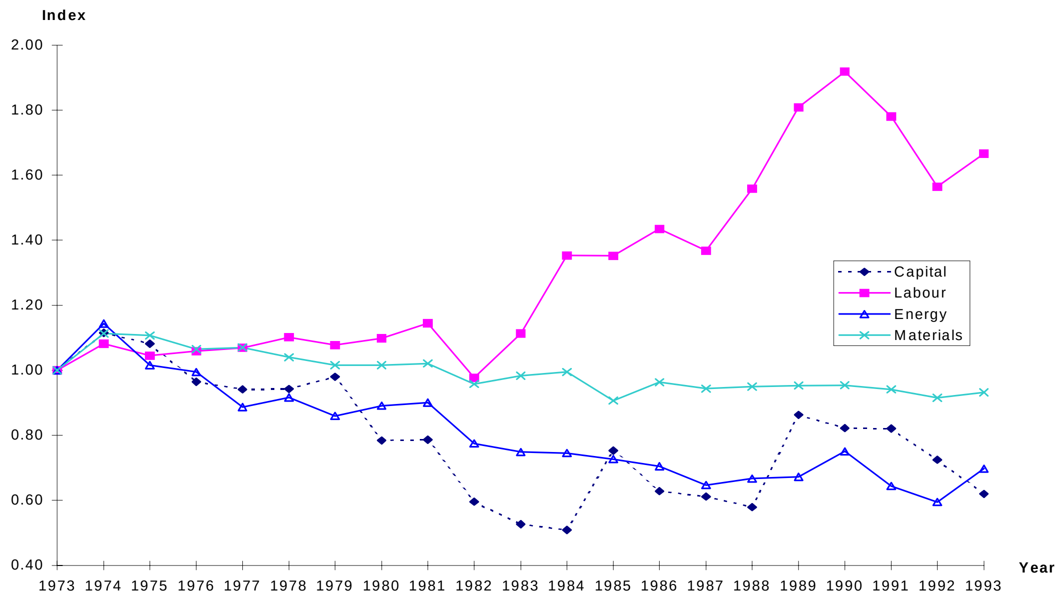
Table 3.1 gives the partial productivity growth for the various inputs based on both value of output and gross value added. The tables indicates the growth rate over the whole time period as well as split up by different time ranges within this period. Growth rates for the time periods are calculated as compound growth rates and time trends. This is to be in accordance with existing growth estimates as presented in section 3.1.1. above. Figure 3.5 displays the partial productivities of capital, labor, energy and material in relation to the value of output.

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

Growth	Capital VO / K	Labor VO / L	Energy VO / E	Material VO / M	K / L ratio K / L	Capital GVA / K	Labor GVA / L
1973-93	-2.36	2.59	-1.79	-0.35	5.07	-4.36	0.49
1973-82	-5.59	-0.25	-2.79	-0.47	5.65	-8.24	-4.37
1982-90	4.10	8.79	-0.40	-0.07	4.51	7.62	12.47
1990-93	-8.97	-4.58	-2.42	-0.74	4.82	-13.84	-9.68
Trend Rate 1973-93	-2.31	3.14	-2.68	-0.82	5.44	-4.61	0.83*

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

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



The growth rates as well as the figure support significant changes in partial productivity in 1982 and 1990. Regarding the whole time period factor productivity was decreasing for all factors except labor. The patterns of change are very similar for all factors. Losses in factor productivity were substantial from 1973-82, followed by a period of progress in 1982-90. During that time, partial productivity switched to considerably positive numbers for capital and labor, and only modest productivity decreases for energy and material. However, from 1990 on productivity again turned negative for all input factors. Figure 3.5 shows a turnaround in energy productivity in 1992. Yet, until 1993 this switch does not offset the downfall experienced in the two previous years. A very similar pattern can be observed for labor.

Labor and capital productivity changes are of particular interest. Labor productivity gains were highest over the time period under consideration, rising at 3.1% p.a. between 1973-93. A significant growth of 8.8% p.a. took place between 1982 and 1990. Before that, in the period of 1973-81, labor productivity increased at a much lower level (1.7% p.a.) followed by a sharp drop in 1981-82. After a peak in 1990 labor productivity begins to decline at a rate of 4.6% p.a. In contrast, capital productivity decreased from 1973-93 at an average rate of -2.3%. Capital productivity highly fluctuates in the time period considered. It shows a strong decrease in the first time range (-5.6% p.a.), high productivity growth in the second period at 4.1% p.a. and shows the highest productivity loss of all factors at almost –9% p.a. in the last time period.

The examination of capital and labor in relation to gross value added rather than gross value of output confirms the results for capital and labor productivity. The increase in labor productivity is to some extent the result of the process of capital deepening, the increasing use of capital per head, indicated by a high growth in the capital labor ratio at 5.4% p.a. Resources have shifted from labor to the use of capital over time.

Energy and material productivities follow similar patterns over time. Energy productivity decreases steadily at an average rate of –2.7% p.a. Productivity loss was high between 1973-82 at -2.8% p.a., improved to lower decline of –0.4% p.a. between 1982 and 1990 and then again dropped considerably to –2.4% p.a. after 1990. Material productivity followed a more moderate path with an average loss of -0.8% p.a.

3.1.2.2 Total Factor Productivity

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

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

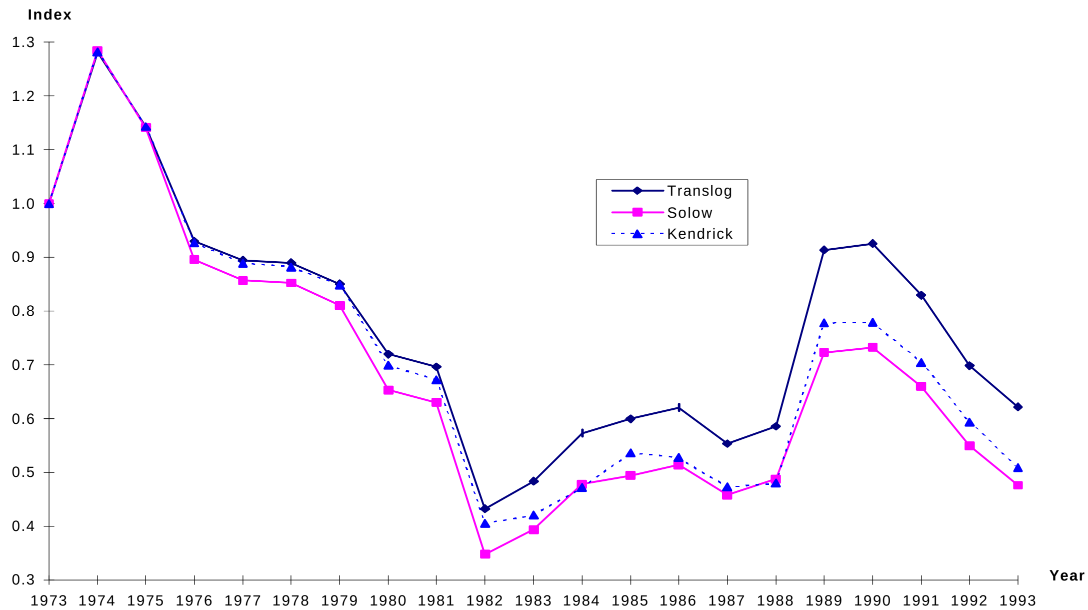
Table 3.2: Total Factor Productivity Growth
(selected time periods, per cent p.a.)

Growth	Translog	Solow	Kendrick
1973-93	-2.4	-3.7	-3.3
1973-82	-9.3	-8.4	-7.3
1982-90	9.5	9.8	8.5
1990-93	-13.3	-13.4	-13.2
Trend Rate			
1973-93	-2.2	-3.6	-3.4

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

The three indices follow very similar patterns. The Kendrick index fluctuates in between the Translog and Solow index. Total factor productivity decreased between 1973 and 1993. The Solow index renders the highest loss at -3.6%. The Kendrick index is slightly lower at –3.4%, while the Translog index is more optimistic accounting for a reduction of only -2.2%. As with the partial factor productivities one can divide three subperiods. The first period 1973-82 on average shows negative growth for the three indices (Translog: -9.3% p.a., Solow: -8.4% p.a., and Kendrick: -7.3% p.a.) reaching its bottom level in 1982. In contrast, the second period 1982-90 gives substantial factor productivity gains at 9.5% p.a. for the Translog index, 9.6% p.a. for the Solow index and 8.5% p.a. for the Kendrick index with a tremendous peak in 1989. Following this peak, total factor productivity declined since 1990 at high rates of -13.2% to -13.4% p.a.

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

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

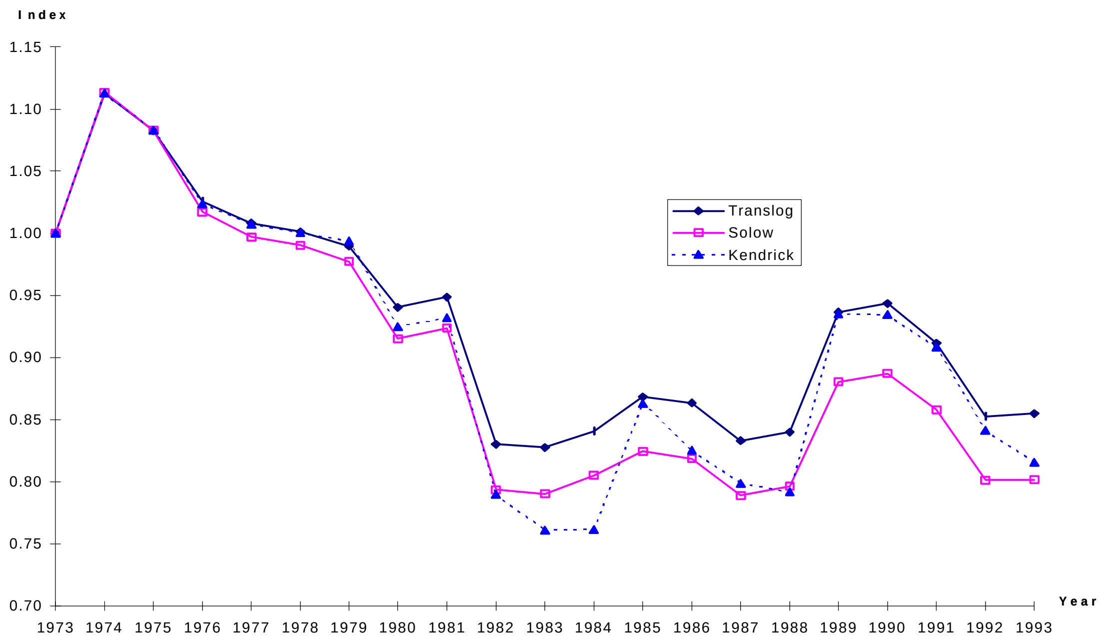
Growth	Translog	Solow	Kendrick
1973-93	-0.8	-1.1	-1.0
1973-82	-2.1	-2.5	-2.6
1982-90	1.6	1.4	2.1
1990-93	-3.3	-3.3	-4.4
Trend Rate			
1973-93	-1.1	-1.5	-1.2

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. The pattern does not differ much from total factor productivity growth. We observe decreasing growth for the whole period at –1.1% p.a. to –1.5% p.a. (depending on the index considered) as well as for the years 1973-82 and 1990-93. In between these two time periods, total productivity is increasing.

Although they point in the same direction, total productivity growth rates for the whole as well as for the subperiods are considerably lower than the ones for total factor productivity. The reason for this can be found in the theoretical setting of measuring productivity. Theory reveals that total productivity growth provides a share of growth in total factor productivity (see Berndt and Watkins, 1981).

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



Decomposition of Growth of Value of Output

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

Table 3.4 shows that overall output in the paper sector measured as average exponential growth of gross output shows a quite positive trend over the period 1973-93 growing at a rate of 5.25%. However, the decomposition reveals that this positive development is mainly due to increased use of factor inputs (6.03% growth in factor inputs). Productivity over the same time period decreases significantly at –0.78% p.a.. The same is true for the subperiod 1973-82. Growth in inputs at 6.82% p.a. drives output growth at 4.75% and at the same time offsets losses in productivity of –2.07% p.a. The period 1982-90 gives a more optimistic picture. With an annual growth of 1.6% productivity gains contribute almost 20% to the overall growth in output of 8.51%. Yet, this upturn is again reversed in the following subperiod (1990-93) where productivity declines considerably implying an overall negative output growth, despite a still increasing use of input factors.

Table 3.4: Decomposition of Growth of Value of Output

Year	Growth (%) in Value of Output	Labor Input	Capital Input	Material Input	Energy Input	Total Input	Total Productivity
1973-93	**5.25**	**0.26**	**1.88**	**2.88**	**1.01**	**6.03**	**-0.78**
1973-82	4.75	0.54	2.78	2.58	0.92	6.82	-2.07
1982-90	8.51	-0.03	0.93	4.54	1.46	6.91	1.60
1990-93	-1.92	0.20	1.73	-0.62	0.05	1.36	-3.29

3.2 Econometric Analysis

3.2.1 Previous Studies

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

Banerji (1975) estimated Cobb Douglas production functions for the Indian industries (including the paper industry) to compute the contributions of labor and capital to gross value added and to isolate the effects of returns to scale and technical progress. He used pooled time series and cross section data. From his estimation he concluded that capital deepening in the paper industry was accompanied by some sort of technical progress between 1946 and 1958. Furthermore, the industry experienced economies of scale during that period.

Mehta (1980) also estimated Cobb Douglas production functions for some energy intensive industries including the paper industries. His sample period encompasses the years 1953 to 1965. He found evidence of capital deepening in the production process but could not conclude any clear trend regarding efficiency improvements.

Ramaswamy et al. (1998) investigate patterns of input substitution and price elasticities for firms which use wastepaper as their primary material input. The authors employ a translog cost function approach with three variable input factors (labor, energy, material) and fixed capital input. They conclude a substitutional relationship between the three inputs. Furthermore, they find a light substitutional relationship between imported and domestic wastepaper, given the total material cost.

3.2.2 Own Estimates

Our results for the econometric estimation of productivity change and patterns of input substitution are received from both the statistical analysis and from estimating a translog cost function approach with four input factors: capital, labor, energy and material. For a detailed presentation of the economic framework, the specifications and the resulting estimations see Roy et al. (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}
	-0.079	-0.0006	-0.017	0.096	0.002	-0.004	-0.0005	0.003	0.003
t-value	(-3.19)	(-0.06)	(-0.98)	(7.58)	(2.43)	(-12.40)	(-0.58)	(11.19)	(0.15)

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

Regarding the cost share elasticities the table shows that the cost shares of material, labor and capital decrease with rising energy prices while the cost share of energy increases with rising energy prices. However, only the values for the material and energy cost share response are statistically significant. The parameter b_{tt} indicates a slight but insignificant deceleration of technical change over time. As shown in the previous section productivity in the paper sector has been decreasing over time. Thus, a significant negative technical change parameter, as expressed by a significant positive value for b_{tt}, would indicate that this decline has been advancing over time. Changes in productivity usually affect all input factors differently. The technological change bias parameters here indicate a significant energy and material using bias as well as a significant labor saving bias. The resulting capital saving bias, however, is statistically insignificant. (Table 3.6).

Table 3.6: Technical Change Bias

	Material	Energy	Labor	Capital
Technical Change	using	using	saving	saving

For the analysis of patterns of substitution and effects of price changes on the immediate use of input factors the own and cross price elasticities are of particular interest. Price

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

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 of Substitution

	Price Elasticity		Price Elasticity		Price Elasticity		Price Elasticity
KK	-1.604	LK	0.068	EK	0.038	MK	0.367
KL	0.051	LL	-0.304	EL	0.104	ML	0.015
KE	0.042	LE	0.154	EE	-0.238	ME	0.026
KM	1.510	LM	0.081	EM	0.096	MM	-0.407

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 –1.6, followed by material price elasticity with –0.4, labor price elasticity with –0.3 and energy price elasticity with –0.2. Cross price elasticities indicated substitutional relationship for all input factors (Table 3.8). Thus, a rise in, for example, energy prices will lead to increased use of material, capital and labor inputs to substitute for the more expensive energy input. Among the input factors, the relationship between capital and material is most elastic. A 10% increase in material price would lead to a 15% increase in capital input while at the same time material use would decrease by 4%. However, it needs to be noted that with most resulting elasticities being relatively small, overall input factors are only moderately elastic.

Table 3.8: Elasticities of Substitution - Qualitative Overview

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

3.3 Discussion

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

As we have seen productivity in the paper sector has been decreasing over the past 20 years. The technological change was accompanied by a capital and labor savings but material and energy using bias. The capital saving bias can be explained by the establishment of many small paper mills following the paper shortage in the early 70s. Government policies promoted the immediate set up of small readily available paper units. These small paper units are generally less capital intensive.

The small paper mills were mostly based on imported technologies. These were readily available and could be set up in any part of the country. Import of such technologies usually implied a labor savings bias. Countries where technologies were imported from were not as labor abundant as India and savings in labor input resulted in substantial total costs savings in these countries. In a country like India where labor is both abundant and inexpensive this feature was not necessarily wanted but had to be accepted with the imports.

The imported technologies by and large were already out of date when imported and have further degraded since. Obsolete technologies, general decay, lack of maintenance, lack of spare parts etc. have contributed to the inefficiencies in the paper sector. After a small peak in 1974, energy productivity decreased substantially over time which supports the econometric results showing a bias in technological change towards the use of energy. Material use also increased per unit of value of output confirming the material-using biased technological change.

Splitting up the time range into three periods (1973-82, 1982-90 and 1990-93) is in accordance with the structural changes in the paper sector. The first period covers the time immediately following the paper shortage with its negative effects on partial and total productivities. In the period 1982-90, the industry recovered with the establishment of slightly more efficient larger paper mills using more modern technologies and appropriating economies of scale. During that period labor as well as capital productivity increased substantially while energy and material productivity decreased at much lower levels. However, the small scale industry still kept its considerable share in total capacity and dampened this upturn.

In 1988, government policy reacted on the slow progress of the paper industry by removing price and distribution controls first for white printing paper only, and later for other paper products as well. The wholesale price index (WPI) for the paper sector shows an increase of approximately 12% between 1988-89 and 1993-94 (as compared to only 8.5% between 1981-82 and 1988-89). Mills could appropriate profitable returns on their products and received incentives to increase capacity utilization and establish more capacity. The peak in total factor as well as total productivity in 1989-90 could reflect an immediate effect of these price policy changes.

From 1990 on, however, the overall economic situation in India became more and more unstable which affected various industries including the paper sector. Growth in production has decreased since then in part due to significant amounts of idle capacity (Table 2.2). Both total factor productivity and total productivity show severe drops that were particularly sharp for capital as well as labor productivity. For the paper sector this downfall in production might have its reasons in the increasing scarcity of raw materials.

In addition, a new policy regarding the removal of statutory controls over production, price and distribution of high quality finished paper affected the paper sector. The change in policy has led to increased supply of paper. Imported paper could now be offered at lower prices pushing domestic paper products out of the market. Additionally, the abolishment of customs duty on imports of paper grade pulp and wood chips was accompanied by a sharp rise in international prices of wood pulp and waste paper in 1994 that escalated the costs of production considerably. Many, particularly small paper mills cannot compete in the market any longer and have to either reduce production or go out of business.

Stricter environmental regulations added to the constraint on raw materials. As mentioned above programs such as the dedicated forest program were implemented implying increasing costs for firms to ensure sufficient availability of raw materials. Furthermore, environmental regulations regarding air, water as well as solid waste effluents forced many small paper mills to close down. Small and medium size pulp and paper mills very often can not economically provide chemical recovery facilities. They therefore suffer from higher emissions as well as higher external energy requirements since recovered chemical and waste products can effectively be used for cogeneration of steam and electricity.

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 paper sector was obtained solely by increased use of factor inputs while productivity over the same time decreased significantly. This indicates that production became relatively more expensive due to the increased share of factor inputs needed. The decomposition analysis emphasizes the important role of material input in paper production. Table 3.4 shows that growth in material inputs presents the main driving factor of output growth for most of the time. Material input is most vulnerable to sector specific changes, in particular with regards to availability and costs of raw materials, as well as to productivity changes and capacity utilization. In the 1980s, the period of progress without major supply constraints and high productivity, material inputs were high and contributed – next to energy inputs - most to growth in output. In the 1990s, however, with increasing difficulties for the paper industry, of all input factors material inputs show the strongest reaction declining at –0.6% p.a. Idle capacity and other sectoral problems led to productivity decay and reduced need of raw materials so that output declined inspite of increased use of other input factors.

The development of energy prices is of particular interest in an energy intensive industry like the pulp and paper industry. An increase in energy prices through policy or world market changes would impose relatively higher costs through the nature of the industry's technological progress towards the use of energy. Technological change and productivity growth would therefore most likely be further reduced. The analysis of inter-input substitution further reveals that energy input is quite sensitive to changes in energy prices. A 10% increase in energy price would reduce energy consumption by 2.4%. All other factors, material, capital and labor, are substitutes to energy use, i.e., demand for these factors would be amplified by an energy price increase. The substitutional relationship is strongest for labor input where a 10% energy price increase would lead to an increase in labor input of 1.5% to compensate for the reduction in energy use. Yet, most other inter-input substitution possibilities are rather weak.

4. Future Development of the Pulp and Paper Sector

4. 1 Ongoing Changes in the Pulp and Paper Industry

Currently, governmental as well as sector initiatives focus on overcoming the acute raw material constraints, implementing and adopting better technologies, increasing production, productivity and efficiency, expanding to economies of scale and decreasing environmental effluents. Various new technologies are entering the Indian market that support these movements.

The government has recognized the significant pressure of the paper industry on the environment and has intensified environmental regulation. Existing standards have been stringent and new ones have been set up. The standards apply to liquid discharges, air emissions and noise pollution Since 1989, the Central Pollution Control Board (CPCB) issues discharge standards even for small paper mills. This has forced many paper mills to switch from agro-based raw materials to wastepaper. (Sharma et al., 1998; Srivastava, 1998)

Demand for paper and paper products is expected to steadily rise in the future, however at decreasing rates. Future paper demand will be determined by certain factors including a) the level of national income, b) the level of industrial production, c) the level of literacy and education, d) the size of population, e) the price of paper, and other related factors such as government expenditure on education, student population, per capital income etc. Some assumptions have to be made regarding the rates of change of these determinants making demand predictions vulnerable to these assumptions being realistic and correct. Table 4.1 shows projections for demand and production of paper products as well as the associated shortfall in production up to the year 2015.

Table 4.1: Demand and Production of Paper - Projections

Year	Demand (mill. tonnes)	Production (mill. tonnes)	Shortfall (mill. tonnes)
2000	4.11	2.56	1.55
2005	5.04	2.76	2.28
2010	6.30	3.15	3.14
2015	7.98	3.32	4.66
Sources: Srivastava (1998).			

Meeting this rising demand will provide a major challenge to the Indian pulp and paper sector. The industry will have to undergo significant modernization and expansion processes. Existing mills will have to renovate and modernize in order to optimize capacity utilization. During this process small agro-based mills are most likely to not survive. They will have to close down due to incapability to meet environmental standards, to operate on economies of scale and to compete against larger agro-based mills for raw materials. Small recycled fibre-based mills are more likely to sustain market forces in adopting measures to cut production costs by importing waste paper or pulp. However, their existence crucially depends on the overall development of the international market price for these materials. Most likely these prices will increase as demand for wastepaper increases worldwide, and wastepaper recovery rates are already very high in many developed countries.

Medium agro/recycled fibre-based mills are expected to possess cost effective potentials for both modernization and expansion. Similarly, large integrated mills have a high potential to undergo the needed modernization and expansion restructuring. Expansion, however, can only be based on forest material to the extent of 25% according the guidelines issued by national forest policy in 1989. They will thus need to mainly be based on recycled fibres, purchased pulp or dedicated forest management.

Table 4.2 provides an overview of proposed expansion and new creation of manufacturing paper capacity differentiated by raw material base. The capacity expansion includes both paper and paper products as well as newsprint. Investment requirements for the expansion and modernization of existing and new mills will rise significantly. Additionally, anticipated import needs for paper and paper products will place further burden on the industry.

Generally, costs for adding new capacity in existing mills are 10-30% lower than for setting up new mills. In numbers, investment costs for a 100 tpd (tonnes per day) forest based plant with chemical recovery is around Rs. 50,000-75,000 per annual tonne, while small agricultural mills, without chemical recovery, require about Rs. 40,000 per annual tonne (Srivastava, 1998). Srivastava(1998) estimate a total investment requirement of Rs. 250 billion over the next 5 years for modernization and expansion of the Indian paper industry.

Table 4.2: Proposed Expansion of Paper Manufacturing Capacities

No. of Units	Raw Material	Total Installed Capacity (mill. tonnes)	Project Cost (Rs. mill.)	Status
4	Bagasse	0.266	20480	2 proposed 2 under implementation
6	Wood	0.275	14320	3 proposed 3 under implementation
3	Waste Paper	0.199	> 3000	1 under implementation
1	Imported Pulp	0.20	7500	approached
Total **14**		**0.94**	**> 45300**	

Source: Srivastava (1998).

4.2 Potentials for Energy Efficiency Improvements

4.2.1 India versus Best Practice

Table 4.3 displays in detail the energy consumption in Indian paper industries split up by section or equipment. The table shows the existing discrepancy between Indian mills and mills abroad due to the problems associated with the sector. Yet, Indian mills' performance cannot be judged by comparing its actual achieved value with world standards. Energy consumption in Indian paper mills differs due to structural differences such as the high share of small and medium size plants of old vintage and the exceptional high share of agro-based paper mills. Substantial energy savings potentials arise due to out-of date technologies employed in India and the non-installation of energy saving devices. Additionally, chemical recovery and cogeneration units improve energy efficiency significantly.

Table 4.3: Energy Consumption in India and Abroad

Section/Equipment	Fuel* (GJ/tonne of paper)		Electricity (GJ/tonne of paper)		Final Energy (GJ/tonne of paper)	
	Indian Mills	Abroad	Indian Mills	Abroad	Indian Mills	Abroad
Chipper			0.40-0.46	0.33-0.35	0.40-0.46	0.33-0.35
Digester	12.5-18.0	8.1-9.9	0.21-0.22	0.15-0.17	12.67-18.22	8.3-10.02
Evaporator	11.5-18.5	7.7-9.4			11.54-18.46	7.71-9.43
Washing & Screening			0.52-0.56	0.42-0.44	0.52-0.56	0.42-0.44
Bleaching	1.6-1.8	0.9-1.1	0.32-0.33	0.24-0.25	1.93-2.18	1.09-1.32
Soda Recovery	2.3-5.1	1.3-2.1	0.61-0.68	0.46-0.49	2.92-5.76	1.74-2.63
Stock Preparation			0.99-1.03	0.59-0.62	0.99-1.03	0.59-0.62
Paper Machine	13.8-18.5	7.7-9.2	1.67-1.71	1.48-1.49	15.52-20.17	9.19-10.72
Deaeratar	3.7-5.5	1.9-3.0			3.69-5.54	1.93-3.00
Utilities and Others			0.89-0.91	0.58-0.59	0.89-0.91	0.58-0.59
Total	46.2-73.8	27.9-36.4	5.40-6.12	4.14-4.50	51.55-79.97	32.00-40.93
Source: Srivastava (1998), TERI (1996), and Mohanty (1997).						

*Fuel used for steam generation - assuming an enthalpy value for steam of 3.0 MJ/kg (Blok, 1992) and an average boiler efficiency of 65% for India and 70% for abroad (based on US boiler efficiency values).

Table 4.4: Specific Energy Consumption Norms for India (proposed)

	Writing and Printing			Kraft			Boards			Newsprint (large integrated mills)	
	Wood based	Agro based	Waste Paper	Wood based	Agro based	Waste Paper	Wood based	Agro based	Waste Paper	Wood based	Bagasse based
Steam t/t	9	5.8	2.8	8.6	4.1	2.3	7	2.2	2.4	4.7	4.7
Power kWh/t	1400	1200	700	1280	650	550	1175	615	685	2000	2000
Steam* GJ/t	38.6	24.6	12.0	36.9	17.6	9.9	30.0	9.4	10.3	20.2	20.2
Power GJ/t	5.0	4.3	2.5	4.6	2.3	2.0	4.2	2.2	2.5	7.2	7.2
Final Energy GJ/t	43.6	29.0	14.5	41.5	19.9	11.8	34.2	11.6	12.8	27.4	27.4
Source: Srivastava (1998).											

*assuming an enthalphy value for steam of 3.0 MJ/kg (Blok, 1992) and 70% boiler efficiency.

The Confederation of Indian Industries (CII) proposed energy consumption norms specific to India that identify best practice energy consumption distinguished by the type of mill

(Table 4.4). The norms that include a much higher share of fuels from internal sources reflect the ambitious goals of the Indian paper industry to catch up and compete with international standards.

Best practice energy consumption weighting factors for various pulping processes and product types have been identified by Worrell et al. (1994) and are given in Appendix B. They distinguish best practice energy consumption for chemical, mechanical and other pulping processes and for five paper grades: newsprint, printing, sanitary, packaging and others. Since their best practice energy consumption factors relate to wood and waste paper based paper production the applicability to India is low. Calculating best practice energy consumption for India based on these factors would give a picture distorted probably towards an underestimate of the actual achievable energy savings potential.

4.2.2 Categories for Energy Efficiency Improvement

The following factors have been identified to play a major role in energy efficiency improvement: Capacity utilization, type of raw material used, technology employed, existence of co-generation (including grid power access) and waste heat recovery facilities, size and vintage of the plant, variety mix and quality of final paper product.

The choice of raw materials used in production substantially influences energy consumption, as well as economic viability and environmental impacts. The use of waste paper as raw material is shown to be environmentally desirable, to consume less energy and to require less investment. As a general rule, it is estimated that waste paper requires 40-60% less energy in producing paper (Kalra, 1989). Waste paper utilization presents a viable addition to the use of agricultural residues particularly in small paper mills that do not or cannot provide chemical recovery.

More technology oriented modernization and expansion options differentiated by processes are provided in Srivastava et al. (1998). Srivastava et al. present in detail the costs and benefits associated with different technologies and give the payback period to appropriate net savings. Most options are cost-effective with payback periods of about three years. They substantially benefit both energy use and environmental impact.

4.2.3 Barriers to Energy Efficiency Improvements

Although integrating modernization and energy savings measures would lead to net savings both in terms of energy and overall costs and payback periods have proven to be short, only few measures have been or are currently being implemented in the Indian pulp and paper sector. Barriers to energy efficiency improvement are both of general and process specific nature.

On the macro level, policy changes towards liberalization together with unstable prices for raw material and energy inputs (high world market prices) as well as for final products (world prices at nearly dumping levels) create uncertainty and pose challenges for the paper industry. In addition, in a capital scarce country like India capital intensive industries focus on reducing capital costs rather than being concerned about energy inputs. Energy costs, however, are not negligible in India. They assume a share of about 20-24% of the total cost of production (Kalra, 1989). Lack of dissemination of information on energy-efficient technologies as well as specific information on savings and benefits of energy savings contribute to the hesitation to improve energy efficiency.

High to medium initial investment requirements associated with energy conservation measures place a burden on the capital scarce economy. Lack of financing capabilities (particularly for small and medium sized units), as well as lack of incentives and investment programs impede the implementation of such measures. Furthermore, since most of the more efficient and modern technologies and equipment can not yet be manufactured indigenously, acquisition of such technology and equipment requires foreign exchange. Substantial outflows of foreign exchange, however, would place further pressure on the overall economy. Though, it should be noted that more and more collaboration agreements between up-to-date foreign and Indian manufactures have been established.

In addition, firm and technology specific barriers to energy efficiency improvements and other modernization options can be observed. Most of the small and medium sized plants are not operating on economies of scale implying that major investment projects can not economically be implemented. Furthermore, the structure of the Indian paper sector with its high share of small and agro-based facilities is very distinct. Due to their negligible share in other countries no research and development activities have been devoted to the improvement of these facilities. With little experience on efficiency improvements in these plants in India both time and investment requirements for development and implementation of these improvements are considered unviably high. For these reasons cogeneration, waste heat and chemical recovery boilers have not been adopted in most of these plants. Lack of power exchange contracts and grid access for the sale of excess power further discourage the installation of these technologies. So far, no regulatory framework for running parallel power has been formulated.

5. Summary and Conclusions

In this paper, we investigated India's pulp and paper sector from various angles. We developed economic as well as engineering indicators for productivity, technical change and energy consumption that allowed us to investigate savings potentials in specific energy use. We discussed our findings within a broader context of structural and policy changes in the sector. The economic analysis showed that productivity has decreased over time with a bias towards increased use of energy and material over labor and capital inputs. The decrease was mainly due to the increased number of small and less productive units that were set up following the acute paper shortage in the early 1970s. In the subperiod of 1982 to 1990 along with the establishment of larger plants as well as first liberalization measures productivity showed increasing though fluctuating trend. Yet, since 1990, the sector has suffered a tremendous downfall in accordance with overall economic recession.

The paper sector has been marked by continuous shortages in supply of various products, especially white printing paper and newsprint. Meeting future demand, which is expected to increase considerably (Table 4.1), will continue to be a challenge as major expansion and modernization efforts would have to be undertaken while raw materials scarcity prevails and price development on international markets is unfavorable to the industry. Future production has to be economically viable and environmentally sound and needs to be more efficient in terms of resources use and production. As seen in Section 2.4 major policy changes have been implemented in the 1990s to overcome the acute problems in the paper sector.

We further pointed out low cost potentials for reducing energy consumption, environmental pollution and improving overall plant productivity. Comparing Indian energy consumption to international energy consumption showed a big gap. Though, due to India's distinct structure which is highly based on agro-based small paper mills best achievable energy consumption for India can not be set equal to international standards. Best achievable energy consumption differs by process type and technology. Energy savings of up to 60% 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. Lack of information about potential savings and existing technologies are among the barriers. Energy and environmental audits could substantially help overcome these barriers.

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. The econometric analysis has shown that with a moderate energy price elasticity of –0.24 a 10% increase in energy prices would lead firms to adjust their input mix in reducing energy input by 2.4%. 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 on a long term basis, substantial further investments in energy efficiency technologies for existing and new plants have to be made. Therefore, sectoral policies should be devoted to the promotion of such investments. Since our economic results suggest that price-based policies although effective in reducing energy use could have a negative long run effect on productivity, and thus welfare, an optimal policy strategy would consist of a mix of regulatory and price based incentives within a set political and economic framework.

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Appendix

Appendix A

Paper Historical Estimates

Author	Method/Measure	Source of Data	Period	Growth Rate
Ahluwalia (1991)	TFPG: TL	ASI	1959-85	-0.7
	PP: Capital			-2.0
	PP: Labor			1.5
	Cap/Lab Ratio			3.6
(1985)	TFPG: TL	ASI	1959-79	0.1
	TFPG: Solow			0.5
Arora (1987)	TFPG: TL	ASI	1973-81	-3.32
	PP: Capital			-3.98
	PP: Labor			-0.62
	Cap/Lab Ratio			3.36
Banerji (1975)	TFPG: Solow	CMI	1946-64	-0.3
	PP: Capital			-0.4
	PP: Labor			6.0
	PP: Energy			-2.5
	PP: Materials			0.2
	Cap/Lab Ratio			6.4
CSO (1981)	TFPG: Kendrick	ASI	1960-77	3.41
	PP: Capital			3.11
	PP: Labor			3.78
	Cap/Lab Ratio			0.67
	TFPG: Kendrick		1960-71	4.58
	PP: Capital			3.71
	PP: Labor			6.11
	Cap/Lab Ratio			2.40
	TFPG: Kendrick		1969-77	1.65
	PP: Capital			2.21
	PP: Labor			0.26
	Cap/Lab Ratio			-1.95
Dabir-Alai (1978)	TFPG: Solow	ASI	1973-78	0.3
	TFPG: Kendrick	I/O Tables		-0.2
	PP: Capital			-0.8
	PP: Labor			0.6
	Cap/Lab Ratio			1.4
Goldar (1986)	TFPG: Kendrick	ASI	1960-70	3.76
	PP: Capital			2.61
	PP: Labor			6.16
	Cap/Lab Ratio			3.55
Mehta (1980)	TFPG: Solow	CMI/ASI	1953-65	-3.3
	TFPG: Kendrick			-6.9
	PP: Capital			-6.9
	PP: Labor			0.9
	Cap/Lab Ratio			7.8
	CD Prod. Function			15.9

Paper Historical Estimates (contd.)

Author	Method/Measure	Source of Data	Period	Growth Rate
Parhi (1997)	TFPG: TL PP: Capital PP: Labor Cap/Lab Ratio		1982-91	1.61 -18.88 3.6 22.48
Pradhan (1998)	TFPG: TL		1963-92 1963-71 1972-81 1982-92	-0.59 -0.2 -0.15 -1.67
Sinha (1970)	TFPG: Kendrick PP: Capital PP: Labor Cap/Lab Ratio		1950-63	0.90 1.61 3.90 2.29
Source: Mongia and Sathaye (1998a)				

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

Appendix B

Best Practice Specific Energy Consumption for Pulp and Paper Production

Process		Fuel (GJ_f/t)	Electricity (GJ_e/t)
Pulping	mechanical chemical others	-2.7 11 11	9.7 -1.8 -1.8
Paper Types	newsprint printing sanitary packaging others	3.2 6.9 5.3 5.0 5.0	2.1 1.9 2.4 1.8 1.3
Source: Worrell et al. (1994)			