TECHNOLOGY CHOICE IN A GLOBAL INDUSTRY: THE CASE OF THE TWIN-WIRE IN CANADA

by

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ABSTRACT

This thesis develops a framework to analyse technology choice and diffusion in 'global' manufacturing industries. The thesis recognises that technology change results from choices made by individual firms, which are made within specific industrial, technological, spatial and managerial contexts. The industrial context refers to the organisational characteristics of industries and the factors affecting supply and demand conditions. The technological context refers to research and development systems and the factors that lead to process and product innovations. The spatial context refers to the economic and political characteristcs of particular nations and regions while the managerial context refers to the investment decision-making processes underlying technology adoption.

The choice of twin-wire paper machines in Canada is examined empirically, using information from published and unpublished corporate records and personal interviews. First, trends in the global demand, supply and trade for pulp and paper are related to the evolution of paper making technology. Second, the research and development process and of the twin-wire paper machine and the factors affecting the process are analysed. Third, the global diffusion patterns of twin-wires, particularly with reference to Canada, are examined. Finally, the investment decision-making processes leading to twin-wire adoptions by six Canadian firms are examined in detail.

The framework provides for an effective understanding of twin-wire choices in Canada. Canada's manufacturing strength in newsprint, the paper grade for which the twin-wire was originally developed, helps explain the relative importance of the twin-wire in the country's pulp and paper industry. Second, the achievement of national technological capability in the design and manufacture of the twin-wire is significant for the timing of twin-wire adoption in Canada. Third, the importance of equipment suppliers in twin-wire development has meant rapid dissemination of information about the technology. Thus Canadian firms have become fast adopters even though Canada has lost its technological capability in twin-wire manufacturing. Fourth, intra-regional

differences in industrial, market and production structures, account for the concentration of twin-wires in Eastern Canada. Finally, the case studies show that past investment history, innovativeness, production structure, investment strategy and decision-making of firms, help explain differences in the timing of twin-wire adoption decisions.

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DEDICATION

To my mother and my sister, who never had the opportunity to go to school yet had the vision to give me a foundation strong enough to support a Ph.D degree.

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CHAPTER I

INTRODUCTION

The Problem

Over the past two-and-a-half decades researchers in industrial geography and other related disciplines such as economics have been increasingly interested in the links between technological change and regional economic development. A dominant focus of this research has been the diffusion of technological innovation. Conventionally, research in this regard has concentrated on analysing the adoption rates of new technologies and the factors affecting these rates. This research has pursued what may be termed an *innovation-adopter-characteristic* approach, an approach which relates adoption rates to innovation and adopter characteristics. These studies have been useful for postulating highly generalised temporal and spatial patterns and good in revealing the complexity of the diffusion pattern (for example Oakey et al, 1982; Gibbs and Edwards, 1985; Rees, Briggs and Hicks, 1985; Mansfield, 1961, 1963, 1971; Davies, 1979). However, in recent years these 'conventional' studies have been criticised for their ambiguity and for their failure to get down to the roots of the factors that lie behind the observed diffusion patterns (McArthur, 1987; Thomas, 1985; Gold, 1981; Gold et al, 1984). In economics, it has even been claimed that the results of these studies have misled governments and business concerns in formulating technological change policies (for example Gold, 1981; Gold et al, 1984). As a result, several pleas have been made by researchers in the field for more studies that will increase the present level of understanding of the technology diffusion process among manufacturing firms and the relationship between technological change and regional development (Thomas, 1985; Gibbs and Edwards, 1985; Easterbrook and Morphet, 1985). In particular, the need for a better conceptualisation of the diffusion process has been emphasised as an important step toward a better understanding of diffusion of technological innovations.

Goals And Objectives

This thesis seeks to respond to this identified research need in technology diffusion studies. It recognises that the technology diffusion pattern that is observable at any time and any place is the outcome of specific and definite choices made by individual enterprises. An explicit incorporation of the question of technology choice into technology diffusion studies will lead to a better understanding of the technology diffusion process. This thesis further recognises that technology choice, to be properly understood, needs to be placed in wider industrial, technological, managerial and spatial contexts. The overall goals of the thesis are:-

1. To develop a conceptual framework of study that will lead to a better understanding of the technology diffusion process and the factors that affect the process.
2. To use this framework to examine the diffusion of the twin-wire paper machine in Canada from 1968 to 1988 with the view to uncovering the main factors that have affected the diffusion process.

More specifically, the thesis seeks to propose a framework for technology diffusion study that is based on the study of technology choice. It seeks to identify the main contexts or environments that are relevant to the understanding of technology choice. It then examines the choice of the twin-wire paper machine in Canada from 1968 to 1988 within each of these contexts. By way of organisation, Chapter 2 of the thesis reviews the relevant literature and proposes the framework in which the main contexts of technology choice are identified as industrial, technological, spatial and managerial. With reference to twin-wire diffusion, the industrial context is then examined in Chapter 3, the technological context in Chapter 4, the spatial context in Chapter 5 and the managerial context in Chapter 6. The summary of the thesis is then presented in Chapter 7.

Research Design

Selection of Industry

There are several reasons for choosing the pulp and paper industry for this study. The first reason is its importance. Paper, which is one of the main products of the industry, is an item which is universally consumed. Besides, the industry occupies a very important place in the economies of many countries. Yet, it is one of the least studied of all the global industries as far as the perspective of this study is concerned. According to a review by Bergston (1983) only five studies existed on diffusion of technological innovations in the forest products industries all of which had been done by economists. The result is that even though there has been a tremendous amount of technological change in the industry over the last 20 years, few detailed studies about these new developments have been made in recent years.

Selection of Technology

Technology in the pulp and paper industry falls into two categories: pulping and paper-making. Pulping technologies are conventionally classified as *chemical*, *mechanical* and *semi-mechanical* pulping. Each of these again can be further subdivided. In the paper-making sector, however, the entire paper-making technology process is embodied in the paper machine. The first of these machines, the Fourdrinier, was invented in 1799 and since that time no major developments occurred until the 1950s and 1960s when the twin-wire was invented and innovated. The impact of the twin-wire on the paper industry, particularly in terms of product quality and scale of production, has been so tremendous that it is regarded as the most significant technological development in the paper sector of the industry since the invention of the Fourdrinier machine. The selection of the twin-wire therefore was based on its importance to the paper industry and the desire to see how firms have behaved, so far, towards such an important innovation.

Selection of Region

Canada is an excellent choice for an investigation of the diffusion of a pulp and paper technology, such as the twin-wire. By value added and also by employment size, pulp and paper manufacturing is the largest and the most important sector of the Canada's largest and most important industry, namely the forest products industry. Besides, Canada is a world leader in the production and trade of paper products, particularly newsprint, the paper grade for which the twin-wire technology was originally developed and currently most advanced. Historically, the Canadian paper sector has been among the top three producers in the world and since the mid-1950s, its pulp and newsprint sectors have led the world export trade in these commodities. With this large newsprint production sector, the Canadian pulp and paper industry not only led the world in innovating the twin-wire machine but by 1984, when this study began, it had the second largest number of twin-wire machine installations in the world, second only to the United States (US). It was therefore considered to be a suitable case study region.

Another reason that makes Canada a good case study region is that the overall goal of the thesis addresses some issues that appears to be potentially important to technological change policy in Canada. On one hand, several studies have indicated that among OECD countries, Canada ranks among the poorest generators of new technologies (OECD, 1968; National Science Foundation, 1975; Britton and Gilmour, 1978; DeMelto et al, 1980; Britton, 1980, 1985; Economic Council of Canada, 1983; Ellis and Waite, 1984; McFetridge and Corvari, 1985). In addition, studies have also established that the diffusion of technological innovation in the manufacturing sector, including pulp and paper, is very slow in Canada, particularly when compared with the US. (Globerman, 1975a, 1975b, 1976, 1981, 1984; Daly and Globerman, 1976). Indeed, in the forest products industry, including pulp and paper, doubts still remain whether Canadian firms can explicitly use technology as a competitive weapon. Moreover, it has been claimed in certain quarters that some efforts by the Canadian government to speed up the diffusion process have only shown that the factors affecting diffusion process in the Canadian manufacturing sector have yet to be understood (The Doody Committee, 1984; McFetridge and Corvari, 1985).

The Time Frame

The 1950–1988 period was chosen because the R&D processes of the twin-wire technology did not begin until the early 1950s and it was not until the end of the 1950s that the first commercial prototypes were developed. This period is also characterised by a number of important developments which were considered to have some interesting effects on technological change in the manufacturing sector and particularly the pulp and paper industry. Among these developments were the post-war boom of population and general economic growth of the 1950s and 1960s; the dwindling of the supply of the natural resource base for certain industries; the environmental pollution issues of the 1970s; the energy crises and subsequent economic recessions in the mid-70s and the early 80s; and the emergence of the new industrialising countries of South-East Asia and the emergence of a new global competition.

Information And Data Sources

In order to pursue the goals and objectives of the thesis information was required on the following topics:

1. Technological change, technology diffusion, organisational behaviour and technology choice.
2. The global pulp and paper industry, its characteristics, technological features and factors affecting the demand and supply structure of its products.
3. The evolution and development of the twin-wire paper machine.
4. The diffusion of all commercial twin-wire installations in the global industry from 1968, when the first installation was made, to 1988 showing among other things, the location, dates of installation, suppliers, machine types.
5. The nature of the decision-making processes leading to twin-wire installations within the Canadian pulp and paper industry.

Information on item 1 was obtained from a wide range of published research material on innovation diffusion and technological change in geography as well as in other disciplines, particularly economics, sociology and on organisational decision-making in business/public administration. Information on item 2 was obtained from published literature in a wide range of pulp and paper journals such as Pulp And Paper International (PPI), Pulp And Paper Magazine of Canada, Pulp & Paper Journal, Pulp & Paper, Paper Trade Journal, Paper, Pulp & Paper Canada, Indian Pulp And Paper Journal, Technical Association of The Pulp And Paper Industry (TAPPI) Journal, Technical Association of the Australian Paper Industry (APITA) Journal, PIMA Magazine, Svenska Papperstinding and books on the pulp and paper industry, including Food And Agriculture Organisation (FAO)'s Yearbook of Forest Products . Pulp and paper equipment manufacturers (PPEMs) constituted the main sources of information for item 3. The data base for item 4 was obtained from the 1984 Twin-Wire Survey Project conducted by the PPI Group in Brussels, Belgium. The data covered installation of twin-wire machines throughout the world from 1968 to 1984. This was updated to 1988 by contacting the pulp and paper equipment manufacturers (PPEMs). Information on item 5 was obtained from personal interviews with the pulp and paper firms (PPFs).

Information And Data Collection

The Simon Fraser University (SFU) Library provided most of the material used in the theoretical development of the thesis. However, the bulk of the research on the industry and the twin-wire technology was conducted in the Pulp And Paper Centre and the MacMillan Libraries of University of British Columbia (UBC). Some research were also done in the two libraries of the Pulp And Paper Research Institute of Canada (PAPRICAN) in Vancouver and Pointe Claire, Quebec as well as the SFU Library, the UBC Main Library and the Statistics Canada Library in Vancouver.

Information from the PPEMs and PPFs were obtained by personal interviews, which were conducted in Ontario, Quebec and British Columbia during August and September, 1988. With respect to the PPEMs, the interview was conducted with 10 senior management personnel of the four leading twin-wire manufacturers, namely Beloit, Valmet, Voith and Black Clawson-Kennedy. The interviews which lasted for about two hours each, focussed primarily on the reasons why the twin-wire machine was development and how it was developed. Respondents were given the opportunity to present narrative accounts on the two parts of the interview during which further questions were asked for further clarification. In the case of the PPFs 16 senior executives from six firms, selected as case studies, were interviewed. Three of the firms were located in British Columbia and three in Quebec. The case study method was used in order to obtain a deeper insight into the technology choice process. The firms were selected because of their location, the number of twin-wires they had installed, the time in which they made their first installations as well as their size, ownership and research and development (R&D) characteristics at the time they made their first installations. The interview focused mainly on the decision-making processes that led to their adoption of the twin-wire and the factors that affected these processes. More details of the two interviews are given in the appropriate chapters.

Pulp And Paper Technology: Characteristics And Trends, 1950-1988

The purpose of this section is to provide some stylised facts about technological capability and change in the pulp and paper industry, that will provide a background for the twin-wire study. The pulp and paper industry is usually classified as a mature industry, an industry in which production technologies, among other things, are considered to have reached their maturity such that opportunities for their further development are either non-existent or are very limited. However, as already pointed out, there has been tremendous technological changes in the various sectors of the industry over the last three to four decades. This section outlines the main features of these developments.

The production technologies of the pulp and paper industry divide into two broad classes: pulping and paper-making, each of which can be further subdivided.

Pulping Technologies

With reference to pulping technologies it is important to distinguish between *mechanical pulp* and *chemical pulp*. *Mechanical* pulps are produced by mechanical ("grinding") mean and principally include *Stone Groundwood (SGW), Pressurised Groundwood (PGW), Refiner Mechanical Pulp (RMP),* and *Thermomechanical Pulp (TMP).* The SGW, first discovered in 1835 and 1836 by Charles Finerty of Nova Scotia, Canada and Friedrich G. Keller of Saxony, Germany respectively, is the oldest mechanical pulping process and remained the main technology for mechanical pulp until the 1950s. In this process, debarked and washed bolts of wood are pressed against rapidly revolving pulpstone (Keays, 1981). The protruding particles in the pulpstone press into the wood and tear off fiber fragments, individual fibers, and small debris or wood flour to constitute a dilute water suspension or *pulp slurry* (Keays, 1981). The slurry is then washed, screened and cleaned successively, with the help of various process equipment, to remove large chunks of wood, knots, small pieces of unprocessed wood, large fiber bundles and small fibre bundles or *shives*. SGW pulp has a fairly high brightness. It is high yield (90 per cent or higher) but is of low strength and requires large amounts of energy.

Since 1950, however, mechanical pulping has undergone the most tremenduous technological development in the pulp industry, starting first in the refining method and later the SGW process. Among these new developments are RMP, TMP, and PGW. RMP developed out of intensive research work in the late 1950s and 1960s following intital efforts in the late 1920s and 1930s. In this process chips, saw dust or wood shavings are fed between two flat rotating disks called *refiners* , of which at least one would be rotating under atmospheric pressure. The disks have abrasive groves specially designed for reducing the chips first into smaller entities and finally into fine fiber material. The pulp produced is similar to that produced by the SGW process, with improved strength but lower opacity (Smook, 1982). In 1960 the first RMP mill to make pulp from chips for newsprint grade was installed by Crown Zellerbach at its West Linn, Oregon mill. The first to use saw dust and wood shavings was installed in 1962 at the Longview Fibre mill, in Washington State. Several other RMP mills including those of Crown Zellerbach at Clatskaine, Oregon in 1966 and United Paper Mills at Kaipola Mill, Finland in 1969, were installed. The RMP process was revolutionary in the sense that it made possible the use of waste wood and saw mill wastes, previously only used by chemical pulping processes, in mechanical pulping. However due to incomplete development of equipment, high use of energy and the need for control the RMP process was not rapidly adopted (Christensen, 1987). Rather, the search for better pulping processes continued, resulting in the *Thermomechanical Pulping (TMP)* process.

The TMP process is a modified RMP process, in which the wood chips are steamed for a short time before or during refining so as to soften the chips. The result is that TMP has a higher percentage of longer fibers and less shives than either SGW or RMP. According to Tillman (1983) TMP was actually invented by A. Asplund of Defibrator Corporation, Sweden in 1939. Initial commercialisation was hampered because of a brown stain which arose from the smearing-over of lignin, from the preheating, to the other fibres. [1] In 1963 two pilot plant installations, one using a 35-ton/day pressurised Bauer refiner and the other a pressurised Defibrator refiner, were started up at the Quebec City mill of the Anglo Canadian Pulp and Paper Company and the Billerud's Joessefors mill in Sweden. The first full-scale commercial installation started up in Sweden in 1968 and in North America in 1973 at Publishers Paper Company, Newberg, Oregon. The high energy requirement of the TMP process, however, became a disadvantage during the energy crises of the mid-1970s and efforts were directed at cutting down on energy consumption. In 1977 a breakthrough was achieved when a method to recover about 70 per cent of the energy introduced into the refiners for reuse was discovered by the United Paper Mills at Kaipola, Finland (Christensen, 1987). The problem with this energy though is it is of lower quality than the high cost electricity

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1. Lignin is outer layer of wood fibre which cements the fibres together.

introduced to the system.

PGW involves the use of pressurised stone grinders in the grinding process of the wood bolts. According to Evans (1980), the concept originated with the ideas that led to the development of TMP. However , it was at that time, considered to be impractical. Subsequently, in 1970s the situation with energy changed. In 1977 MoDoCell AB of Sweden contacted Tampella of Finland about the possibility of converting one of the Tampella grinders at its Burea mill to pressurised operation for testing purposes and whether Tampella would be interested in a project of that nature. The first full-scale trial began in the summer of 1977 at the Burea mill in Sweden and over a period of six months, about 400 test grindings were done. The first data were released in March 1978 showed that the pulp was stronger than the normal SGW and in fact close to that of TMP. However, energy consumption was only 60 per cent that of TMP and equal to or lower than that of SGW, while printability was better than that of TMP (Evans, 1980). These results were so promising that MoDoCell ordered a 50-ton per day (tpd) unit for the Burea mill. Tampella also installed another 50-tpd unit at its own Anjala paper mill at Inkeroinen, Finland to permit further development. By 1980, four paper companies in three countries had installed among them 15 pressurised grinders, including Canada and the US.

Chemical pulp is produced by chemical processes, which involve cooking the wood chips in an acqueous solution of appropriate chemicals at a high temperature and pressure to remove the lignin in the wood. There are two main processes of chemical pulping: the *Sulphate or Kraft* process and the *Sulphite* process. In the *Sulphite* process, wood chips are cooked in a mixture of *sulphurous acid* and *bisulphite ion*, in large steel shell called the *digester*. The duration of the cooking time depends on the desired end product. However, within 1 to 1.5 hours of the remaining cooking time, the heating is stopped and the pressure reduced. The cooked chips are then 'blown' into the *blow pit or blow tank* from the digester, during which process they are converted into pulp. Large quantities of water are sprayed on to the pulp in a multi-stage washing process to remove residual liquor. The pulp is then subjected to the same screening, cleaning, thickening and storage treatments as mentioned in the case of mechanical pulp.

The *Kraft* process involves the same general procedures as the sulphite. However, there are some significant diferences. First, the cooking liquor is a solution of *sodium hydroxide* and *sodium sulphide*. Second, while the Sulphite process uses a *batch* cooking process, the Kraft cooking process can be either *batch* or *continuous*, but mostly continuous. The difference between the two is that in the continuous cooking process, the cycle of events that take place in the digester during the batch cooking process, is carried out sequentially at different sections of the digester. From the digester, the cooked chips enter the blow tank from where the pulp is washed by a process called *Brown Stock Washing* . The spent energy and cooking liquor are then recovered by a series of processes, called *Kraft Recovery System*, for re-use. The pulp is then treated in the same way as the sulphite pulp for further use in paper-making. A third type of chemical pulp is *dissolving pulp* which is the pulp used for such products as rayon and cellophane. Dissolving pulp is produced by either a modified kraft or sulphite process which aims at removing not only the lignin but also the *hemicelluloses* [2]

Like the mechanical pulping process a number of developments have taken place in the chemical pulping processes. In sulphite pulping, these developments were due to two reasons: the limited number of wood species that could be used and the unmanageable effluent problem. With increasing competition from Kraft pulp, intensive research work began on the waste liquor problem and on the possibility of finding new cooking bases. During the mid-1950s two important developments occurred, both of them in Canada, when the *sodium-based pulping* and the *magnesium-based pulping* (the *magnefite process*) were discovered. Using sodium alone as the cooking base, the sodium-based method produced pulp of higher brightness and strength than the usual sulphite method, while the magnefite process which uses magnesium alone as the cooking base, extended the tree species that could be sulphite-pulped.

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2. Hemicelluloses refer to the polymer of five different sugars in the structure of trees.

Subsequent to the introduction of magnesium and sodium as cooking bases, a number of two-stage pulping processes were developed among which included the *Two-Stage Stora Process, The Sivola Process*,and The Two-Stage Magnesium Process. The Stora process developed in Sweden uses sodium base in the first stage and sulphur dioxide in the second stage. The Sivola process uses alkaline sulphite in the first stage and pure sodium bisulphite in the second stage. Corresponding recovery systems that have been developed include the *Mead Process*, the *Sivola Recovery Process*, the *Stora Recovery Process* and the *SCA-Billerud Recovery Process* (Wenzl, 1965).

In Kraft pulping, the most significant developments have taken place in the process equipment or machinery section, particularly the digester, which is at the heart of the whole process. According to Smook (1982), the Kamyr continuous digester, invented in 1938 by Kamyr A.B of Sweden and installed for the first commercial application in 1952, has since undergone some further significant changes. Among these are conversion from hot to cold to conserve pulp in 1958; inclusion of difussion washing stage in 1962; modification of the chip chute and addition of in-line drainer in 1968; atmospheric presteaming of the chips in a special design chip bin to optimise chip steaming in 1974; development of vapour phase digester for sulphite and prehydrolyzed kraft production in 1967, and the development of the two-vessel system with separate impregnation in 1972. Another significant development in continuous digesters is the *IMPCO (Improved Machinery Company) digester*. This digester which was the outcome of a joint effort between the Hammermill Paper Company and the Improved Machinery Company, both of the US., was developed to operate on any of the major pulping processes (Carlsmith, 1959). In contrast to the Kamyr system, this digester is a vertical upward-type flow and is essentially characterised by two important devices: a *Chip Lifter* to lift the chips up through the digester, and a *Skew-jector*, to handle both chips and cooking liquor. The development process began in 1952 and in 1959 the first commercial application was installed. However, it was not until the 1980s that the digester became widely accepted by the industry.

In addition to the developments which have taken place within each of the two pulping processes considerable developments to combine chemical and mechanical pulping processes have also taken place resulting in a whole range of pulping processes called *Semi-Chemical and Chemi-Mechanical* processes. In *Semichemical pulping* wood chips are partially softened or digested with chemicals first, and then processed by mechanical means. These processes include the *Neutral Sulphite Semi-Chemical (NSSC)* process, *Acid Sulphite Semi-Chemical* process, *Bisulphite Semi-Chemical* process, and the *Kraft Semi-Chemical* process. In contrast, *The Chemi-Mechanical* process is the same except that chemical treatment is claimed to be much milder while the mechanical pulping process is more drastic. Among these processes are the *Cold-Soda Chemi-Mechanical pulping, the Hot-Sulphite Chemi-Mechanical pulping, the Chemi-Groundwood pulping* and the *Chemi-Thermo-Mechanical (CTMP) pulping* (Table 1.1).

Bleaching

Unbleached pulps usually exhibit a wide range of whiteness. The brightest is sulphite, with about 65 brightness and the darkest is kraft. In the case of mechanical pulps, mainly depending on wood species used, brightness may range from 50-65. In any case unbleached wood pulp is usually brown to tan in colour largely as a result of the presence of lignin or extractives from the heartwood. Thus when manufacturing paper for books and other purposes in which whiteness is important, the fiber must be brightened by *bleaching*, which involves the use of various bleaching agents on the pulp in a stepwise and sequential manner. Some of the common bleaching sequences currently used are given in Table 1.2. Thus, CEDED is a sequence of bleaching involving chlorination, extraction and chlorine dioxide. Initially, chlorine dioxide was used in the later stage of a multi-stage bleaching. During the 1960s, the sequence CEHDED became important but later inclusion of *hypochloride* became economically unjustifiable because the cost advantage hypochloride had over chlorine dioxide ceased to exist so the sequence CEDED became more attractive. In 1964, Rapson and Anderson of US. introduced the displacement bleaching process when they showed that very rapid bleaching can be performed when bleaching chemicals are displaced through a pulp mat

Table 1.1 **Summary of Pulping Processes**

Classification	Process Name	Wood Used	Wood Form	Yields	Soft Wood	Hard Wood
Mechanical	Stone Groundwood	Softwood†	Bolts	90-95%	5	3
	RMP	Softwood†	Chips	90-95%	5-6%	3
	TMP	Softwood	Chips	90%	6-7	
Chemi-mechanical	Chemigroundwood	Hardwood	Bolts	85-90%	-	5-6
	Cold Soda	Hardwood	Chips	85-90%	-	5-6%
	CTMP					
Semichemical	NSSC	Hardwood	Chips	65-80%	-	6
	High Yield Sulfite	Softwood†	Chips	55-75%	7	6
	High Yield Kraft	Softwood†	Chips	50-70%	7	6
Chemical	Kraft	Both	Chips	40-50%	10	7-8
	Sulfite	Both	Chips	45-55%	9	7
	Soda	Hardwood	Chips	45-55%	-	7-8

† = mostly
Source: Smook, 1982 p. 42

Table 1.2 **Common Bleaching Sequences**

Sequence	Explanation
Chlorination (C)	Reaction with elemental chlorine in acidic medium
Alkaline Extraction (E)	Dissolution of reaction products with NaOH.
Hypochlorite (H)	Reaction with hypochlorite in alkaline solution.
Chlorine Dioxide (D)	Reaction with chlorine dioxide in acidic medium.
Peroxide (P)	Reaction with peroxides in alkaline medium.
Oxygen (O)	Reaction with elemental oxygen at high pressure in alkaline medium.
D or C	Admixtures of chlorine and chlorine dioxide.

Source: Smook, 1982 p. 154.

rather than mixed into the pulp in the conventional way. This method also removed the washing that was needed. The development of diffusion cleaners (Kamyr) made this concept applicable and Kamyr succeeded in mounting a number of diffuser units in a single tower to undertake a multi-stage bleaching sequence (Smook, 1982).

In addition to these developments, considerable efforts have also concentrated on *oxygen bleaching* resulting in a number of commercial applications. These have focussed largely on using oxygen as a delignification agent before bleaching with chlorine chemicals. Most of the commercial applications have been high consistency bleaching (about 20-30 per cent) temperatures at 90 – 130° C. In 1978, a process of low-consistency oxygen bleaching, in which hot stock at 110 – 150° C and 3-5 per cent consistency is pumped through a series of pipeline mixers where gaseous oxygen and caustic are added at intervals was proposed. This new process is reputed to allow up to 80 per cent delignification without magnesium salt, which is usually added in the old oxygen bleaching process as a protector against severe degardation of the cellulose. In 1980, the world's first *medium consistency (MC)* oxygen bleaching was started up at the Moss mill of M. Peterson & Sons A/S of Norway. In 1981, another oxygen bleaching method was reported by Markham and Magnotta of Black Clawson Company. In spite of these developments, cellulose degradation continue to be a limitation to the full application of high-consistency oxygen bleaching. Another change is the replacement of *zinc hydrosulphite* by *sodium hydrosulphite* in the bleaching of mechanical pulp, which occurred in the 1970s as a result of zinc toxic contaminants in the effluent discharges.

Paper-Making

Variations do exist as to how each of the paper grades are manufactured. However, the general technology of paper-making is the same. The process usually begins with preparation of the stock, which involves four sequential and inter-related processes.[3] First, the dry pulp is dispersed into water to form a *slurry* of very low consistency. Next the fibre is *beaten and refined* by subjecting it to mechanical action so as to develop its best paper-making characteristics. A wide variety of *additives*, mainly chemicals, are added to the pulp to impart specific properties to the paper product. Finally, the various components of the fibre material and non-fibre material are then blended to form a *furnish* for papermaking (Smook, 1982 p. 179).[4]

After the stock has been prepared, the rest of the paper-making process is entirely carried out by the *paper-making machine*, which is a collection of machines consisting of a *Forming zone*, a *Press section*, a *Dryer section*, *a Calender section* and a *Winding section.* In the Forming zone, the furnish, passing through the *headbox* of the machine, is deposited on a moving, fine-woven and endless screen or *wire.* About 95 per cent of the water content is then removed by drainage through the wire. Since the fibres are of the same length as the openings in the wire many of the fibres are

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3. Stock is the name given to the wet pulp at any stage of the paper-making process.

4. Furnish is the specific mixture of raw materials, both pulp and chemicals, from which a particular grade is manufactured. This usually may consist of a combination of both chemical and mechanical pulp.

drained away at the initial stage. However, as the sheet begins to form, the retention rate increases leading to formation of a very wet but strong mat. The mat is then transferred to the Press section, where it goes over a series of presses for further water removal. Next, the sheet enters the Dryer section, where it passes over a series of heated cylinders, for most of the remaining water to be removed. The sheet then goes through a metal of calender stack, in the Calender section, to reduce the thickness and smoothen the surface. In the Winding section, the dried or calendered paper is wound on to a reel. The section comprising the headbox and the forming zone is usually referred to as the *Wet End* while the press, the dryer and the the *Dry End.*

In order to meet the changing needs of the printing world, it has been necessary to improve upon the surfaces of sheets formed and one of the ways of doing this is by *coating*. The process involved surface-treatment of the sheet with a water suspension of a mineral pigment, usually clay, and a binder. There are two ways of doing this, either *on-machine* or *off-machine* coating. In either way, the coated sheet is dried either by *hot air impingement* or *infrared drying*. A considerable amount of shrinkage can occur during the drying and to improve this *supercalendering* is carried out, in which the sheet is passed through a series of vertically arranged alternate hard metal and soft rolls of compressed fibrous material to produce a glossy surface (Smook, 1982).

At the beginning of the 1950s, there were two main types of paper machine, namely, the Fourdrinier and the Cylinder machines. The distinguishing feature of these two machines lay in their forming zones. The forming zone of the Fourdrinier consisted of a flat moving wire supported in a horizontal position by the Fourdrinier table, while the forming zone of the Cylinder machine consisted of a cylinder mold surface covered with fine wire cloth, and revolving in a vat of paper stock. Invented in 1799 and 1800 respectively, both the fourdrinier and the cylinder had undergone a a number of changes. However, these were not enough to meet all the needs of the industry. The result is that since 1950 some significant developments have taken place in both the wet end and the dry ends of the two machines.

Four major developments took place in the wet end section (Thorp, 1982). The first was the development of the *Hydraulic headbox* introduced in 1954 by the Beloit Corporation of Beloit, Wisconsin. This headbox eliminated the free surface which used to exist on the top of the stock and made possible the use of stationary elements to even the flow and generate turbulence at a higher velocity (Wahlstrom, 1981). An equivalent of this for the Cylinder machine was the *multi-layered headbox*. The second was the development of *Hydrofoils* in 1955-1956 by George Burkhard and Peter Wrist of Ontario Paper's Baie Comeau mill. These replaced the table rolls on the Fourdriniers and thus eliminated the severe disruption problems associated with the pressure pulse on the table rolls of the Fourdrinier machine. The third was the development of synthetic fabric by Holden and Schiff in 1958 to replace the metal wires thereby increasing the wire life by more than ten times. The fourth and in fact the most important took place in the forming zone itself, where *multi-ply formers* and the *twin-wire formers* replaced the previous forming sections of the Cylinder and the Fourdrinier machines respectively.

Among the multi-ply formers were such machines like the Semi-Rotoformer, the Rotoformer, the Stevens-Former, the Suction Former, the Hydraulic Former and the Ultra-Former which were all develped and commercialised in the 1960s, while the twin-wires included such machines as the Verti-Forma and the Top Flyte developed by Black Clawson of US.; the Papriformer and the Dynaformer developed by the Pulp And Paper Reasearch Institute of Canada and Dominion Engineering Works of Canada; the Periformer by Karlstadts Mekaniska Werkstads (KMW) of Sweden; the Symformer by Valmet of Finland; the Duoformer by J.M Voith of FRG and the Bel Baie, the Bel Bond, the Bel Roll, and the Bel Form by the Beloit Corporation of the US. The multi-ply formers improved multi-ply forming of paper board while the twin-wires have made significant advances in improving the product quality of newsprint in particular and increased production capacity since they are also high speed machines.

Some significant changes have also occurred in the dry end particularly with the Fourdrinier machine. In particular some changes were made in the *Press* and the *Dryer* sections. However, since 1950 the most significant advances have been made in the Press section. These include the *Grooved-roll Press* introduced by Beloit in 1963, the *Fabric Press* and the *Extended Nip Press* also introduced by Beloit in 1981. The last-named in particular has the reputation for achieving the maximum dryness (Wahlstrom, 1981). Another significant development in the Press Section is the *Vacuum Pickup* which was first applied commercially in 1954. Before the vacuum pickup the sheet was transferred from the Wire to the Press section over an *open draw* without support. The tension needed to pull the web to the first press felt was provided by the speed differential between the press and the wire sections. However as the tension increases exponentially with speed, runnability problems were encountered at higher machine speeds and such grades as lightweight paper products would break during the transfer. In the vacuum pickup transfer system, the sheet is picked off the wire by the felt which wraps a vacuum roll at the point of contact (Smook, 1982).

Process Control Computer Systems

Another technological development, which has taken place over the study period and which has affected the entire mill system, that is both pulping and the paper sector, is the use of computers in millwide process control. The primary reason for this is to achieve more consistent product and acquire better decision-making tools for operating (Fadum and Edlund, 1989). Before the use of computers, the need for controlling the basis weight and moisture on the paper machine led to the equipment of paper machine with a number of devices (Williams and Hass, 1967). However, these devices measured only basis weight moisture but could not control the parameters. In addition there were problems with the extent of accuracy of these measures. In 1961, the first computer installation in the pulp and paper industry took place at Potlatch Forest Industries in Lewiston, Idaho. The installation was applied to a paper machine. By 1968, an estimated amount of 50 computer installation systems had been installed in the US. For reasons such as lack of reliable sensors, lack of knowledgeable people about process control, and large size of computers and low uptime, many of these early projects failed (Williams and Hass, 1967; Fadum, 1981).

During the first part of the 1970s, an innovative supplier strategy introduced by Measurex Corporation, which had just been formed in 1968, not only revived but also revolutionarised interest in the use of computer process control among pulp and paper firms as well as supplier firms. Before this time, most of the computer installations were rented. Measurex introduced a package which guaranteed pulp and paper firms to return installed computers, at no cost, in case their performance did not meet expectations. In the period that followed other supplier firms such as Industrial Nucleonics (now AccuRay), Electronic Associates (EA) of Canada (now Sentrol) and Taylor Instruments entered the market.[5] Efforts were also made to introduce control systems in the pulping sector by suppliers like Nokia, Foxboro, and MoDo Chemetics. By 1975, operations in the bleach plant, continuous and batch digesters were all being controlled by computers. Between 1975 and 1980 interest continued to surge. Some pulp and paper firms researched and introduced their own control systems, among which was the *hydratol* developed by Westvaco in 1977. However, the most significant of all the developments during this period was the introduction of distributor micro-processor-based control systems which were developed by Honeywell in 1975. This system replaced formerly large control panel with video screens and dramatically transformed the control room. By 1981, there were about 32 different suppliers of this system , world-wide. The focus of process control also became the need to use timely information to make decisions that affect the profitability of the mill.

The foregoing account shows that even though it is a mature industry, the pulp and paper industry has gone through very spectacular technological changes over the past four decades. Technologies which were invented and perfected during the Industrial Revolution, such as the Stone Groundwood pulping processes and the paper-making machines, have all undergone the most radical changes unprecedented in the history of the industry. Over a period of 30 years the

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5. Some of these firms faded out in the competition that followed. For business reasons, EA went bankrupt but because of its expertise in sensor technology, a Candian venture capital bought it in 1975 under the new name, Sentrol. By 1981, however, it had become one of the three leading firms in the supply of paper machine sensors and control systems. Taylor Instruments, however, quietly discontinued its paper machine systems in the mid-1970s.

mechanical pulping process, which had not changed for a period of over 100 years, has become more variagated. Over the same period , the paper machines which reached perfection by 1880 have achieved a considerable increase in speed and width as well as improvement in product quality and the use of computers in millwide process control has greatly enhanced timely availability of information needed to make decisions that are fundamental to profitability of the mill. This thesis focusses on the twin-wire paper machine.

CHAPTER II

TECHNOLOGY DIFFUSION IN THE MANUFACTURING SECTOR: A FRAMEWORK FOR ANALYSIS

The purpose of this chapter is to develop a framework for analysis of technology choice made by firms in *global industries*, which is relevant for understanding technology diffusion in the manufacturing sector. The basic tenet of the framework is that technology diffusion can best be understood as a direct result of technology choice and that this choice needs to be placed within an appropriate decision-making context. Existing diffusion studies representing the conventional innovation-adopter-characteristic approach are reviewed. Next, the nature and elements of the *technology choice* approach are proposed and discussed. The main focus is on the geographic literature, particularly research in industrial geography. However, considering the multi-disciplinary and inter-disciplinary nature of the diffusion process, relevant references and material from other disciplines, particularly economics, sociology and organisational behaviour are used as appropriate. Throughout the thesis the term *technology* implies industrial technology, and will mean the knowledge and methods, including enterpreneurial experience, professional know-how as well as capital equipment which embody these methods and know-how, that are necessary for the production and distribution of goods and services (Santikan, 1981). A *global industry* will also refer to an industry which produces a universally consumed product, is represented on all the continents of the globe and is influenced by forces that have global, national and local origins. Other concepts are defined when and where necessary.

Diffusion Studies

Following Schumpeter (1939), *diffusion* is generally considered as one of the three processes of technological change, the other two being *invention* and *innovation*. Invention usually refers to anything that adds to the set of known technological possibilities. *Innovation* is generally defined as the use of ideas or objects considered to be new to the user and *diffusion* is defined as the spread of innovation (Brown, 1981; Sahel, 1981; Rogers, 1962). In geography, diffusion is the most widely studied of the three interrelated processes. This is not only because diffusion is readily measurable and amenable to quantitative approaches but also because the rate at which new technologies spread in any given region has come to be considered as a crucial determinant of the rate of that region's economic development. Technology diffusion is therefore of interest to both policy makers and researchers.

Conceptual development of innovation diffusion models began in the non-manufacturing sector and largely by sociologists, anthroplogists and psychologists, such as Tarde (1903); Chapin (1928); Linton (1936); Pemberton (1936b); Bowers (1938); Ryan and Gross (1943); Brunner and Postman (1947); Lionberger (1949, 1951); Wilkening (1949, 1950a, 1950b, 1951); Dodd (1953, 1955); Dodd and Winthrop (1953); Barnet (1953); Spicer (1953); Bright (1964); Rogers (1962), and a few economists, notably, Griliches (1957). These studies pioneered and established some of the empirical regularities which have come to charactrised 'conventional' diffusion studies. Thus Tarde (1903) proposed among other things the *S-shaped* logistic curve as the standard shape for innovation diffusion, which received confirmation from Chapin (1928), Dodd (1953) and Griliches (1957). Ryan and Gross (1943) identified four classes of adopters, on the basis of when they adopted the hybrid corn, as *early adopters, early majority, late majority* and *laggards*. They also recognised adoption as decision-making process consisting of three stages, namely, *awareness* , *trial* and *adoption*. Rogers (1962) extended these categories to include awareness stage, interest stage, evaluation stage, trial stage and adoption stage.

With reference to factors relevant to the interpretation of diffusion patterns, the sociological studies emphasized the concept of *congruence* , that is technological innovations are likely to be more readily accepted if they can be related to an existing cultural pattern. Thus, Linton (1936) recognised that the characteristics of innovation affected its rate of adoption. Bowers (1938) investigated rural-urban differences in the adoption on innovation and established a relationship between such factors as city size, region and urbanness and the rate of adoption. Bruner and Postman (1947) showed that the relative advantage of any given innovation is a function of individual perception. They argued that each individual perceives a new idea, process or product in terms of his/her past experience, technical competence, present needs and future expectations. Since these characteristics differ from one adopter to another and also from one propagator to another, the diffusion process is in their view probablistic. Other relevant factors identified by these studies include whether or not an innovation is compatible with societal norms (Lionberger, 1949, 1951; Wilkening, 1949, 1950a, 1950b, 1951; Barnet, 1953; Spicer, 1953; Kivlin, 1960; Rogers, 1962; Bright, 1964); whether or not an innovation is complex (Kivlin, 1960; Rogers, 1962); the role of change-agents (Spicer, 1953; Rogers, 1962; Bright, 1964); the characteristics of social network (Coleman, Katz and Menzel, 1957); interorganizational network (Walker, 1969) and the educational characteristics of potential adopters (Rogers, 1962; Hayami and Ruttan, 1971). In contrast, Griliches' (1957) study emphasised *profitability* as the most important explanatory factor of the diffusion pattern.

Within geography, Hagerstrand (1952, 1953, 1965a, 1965b, 1967a, 1967) pioneered studies of a similar nature to those of the sociologists. He postulated that adoption of innovation was primarily the outcome of learning. The flow of information and its geographic structure was considered the most critical factor. The fundamental step in examining the diffusion process is the identification of the spatial characteristics of information flow and resistance to adoption . Hagerstrand confirmed the S-shaped cumulative adoption curve and proposed two hypotheses concerning the spatial spread of innovations, namely, the *hierarchy effect* and the *neighbourhood* or *contagion effect.* The hierarchy hypothesis stated that in an urban system, the diffusion of innovation is expected to proceed from larger to smaller centres while the neighbourhood hypothesis stated that diffusion of innovation is expected to occur in a wave-like manner, first hitting places nearby the initial diffusion center rather than locations farther away. Hagerstrand pioneered Monte Carlo simulation to test and establish the neighbourhood hypothesis.

Hagerstrand's study became a model for geographical studies and a tremendous amount of work was carried out by geographers on various themes that emerged, some confirming and others contradicting the two major hypotheses. [1] Among the latter group, Brown's (1968, 1975, 1981) studies stand out as the most important. Brown attributed the inconsistencies between Hagerstrand's theoretical model and empirical regularities to the fact that the adoptive perspective which underlies the model did not consider the supply-side issues of innovation. He argued that the mechanisms through which innovations are made available to potential adopters are of equal, if not greater, importance. It is therefore necessary to consider supply as well as demand factors. To this end Brown postulated what he referred to as the *market and infrastructure perspective* of innovation diffusion. In this perspective, the supplier of the innovation is seen as an active agent of diffusion who is involved in three main activities: an initial activity, which involves establishment of the diffusion agency; a second activity which involves establishment of the innovation through such strategies as infrastructure development, organisational capabilities, pricing, promotional communication and market selection and segmentation. The third activity involves implementation of the strategies to induce potential users to adopt the innovation.

While geographical and sociological studies of innovation diffusion continued to be largely conducted in the non-manufacturing sector, economists soon began to work on the manufacturing sector. Consequently, when economic geographers began to study diffusion in the manufacturing sector, they turned to the economic tradition while the literature on diffusion in the non-manufacturing sector was hardly referred to. Diffusion studies by economists, strongly influenced by Mansfield (1961, 1963, 1968, 1971, 1977), drew heavily upon the analogy of the spread of epidemics in which the rate of adoption (infection) by the population of potential adopters (those at risk) depends on the characteristics of the innovation (infectiousness) in terms of investment required and upon the characteristics of potential adopters. In particular, it was argued that the economic advantage a firm perceives by introducing an innovation has to be weighed against the risks

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1. For a comprehensive review of these studies and on the general geographical literature on diffusion of innovation among the non-manufacturing sector, see Brown (1981).

and doubts in introducing the innovation, the level of uncertainty, and the extent of committment required. On the one hand, if the innovation is adopted early, the risks and uncertainties are higher but the competitive advantage and the profit gained can also be higher. On the other hand, if the firm adopts an innovation late, the risks and uncertainties are lower but so will the potential gains. To the extent that firms wish to minimise risk, not many would want to adopt the innovation early and those who would, should have special characteristics to enable them do so. Under these conditions, the trade-off between risk and uncertainty, on one hand, and profitability, on the other, leads to different adoption times which over time conforms to an S-shaped logistic function (Chen, 1983).

Mansfield (1961) hypothesized that the proportion of "old outs", $\lambda_{ij}(t)$ at time t that will introduce the innovation at time $t+1$, defined as:

$$\lambda_{ij}(t) = m_{ij}(t + 1) - m_{ij}(t) / n_{ij} - m_{ij}(t) \qquad (2.1)$$

where $m_{ij}(t)$ is the number of firms in the ith industry having introduced the jth innovation, at time t; $m_{ij}(t + 1)$ is the number of firms in the ith industry having introduced the jth innovation at time $t + 1$ and n_{ij} *is the total number of firms in the* ith industry having the potential of using the jth innovation,

is a function of the relative profitability of installing the innovation over others, π_{ij} ; the investment required to install the innovation as a percentage of the firm's total asset, S_{ij} and some unspecified variables. Allowing the function to vary among industries, equation (2.1) becomes

$$\lambda_{ij}(t) = f_i(m_{ij}(t) / n_{ij}, \pi_{ij}, S_{ij}...) \qquad (2.2)$$

Profitability is measured, in this case, by dividing the average pay-out period required by the firm by the average pay-out period for the innovation. Mansfield reasoned that first, $\lambda_{ij}(t)$, would increase over time. Second, profitability would exert an important influence on $\lambda_{ij}(t)$: the more profitable the investment the greater the chances that the firm will adopt the innovation. Third, given equally profitable innovations, $\lambda_{ij}(t)$ will be smaller for those innovations requiring larger investments. Finally, given equally profitable innovations, $\lambda_{ij}(t)$ is likely to vary among industries because of inter-industry differences in risk aversion, market competition, attitude of the labour force toward innovations and financial standing.

On the basis of these reasons, Mansfield made five assumptions: first, the number of firms that have introduced the innovation in time *(t)* can vary continuously; second, that $\lambda_{ij}(t)$ can be adequately approximated by a Taylor's expansion that drops third and higher order terms; third, the coefficient of $(m_{ij}(t) / n_{ij})^2$ is zero; fourth, time is measured in fairly small units; fifth, the limit of the number of firms that have introduced the innovation as we go back in time tends to zero. With these assumptions Mansfield derived the equation of the diffusion curve as

$$m(t) = n\,[\,1 + e^{-(\alpha + \phi t)}\,]^{-1} \qquad (2.3)$$

On the basis of this equation, Mansfield concluded that the growth over time in the number of firms having introduced an innovation *m(t)* should conform to a logistic function just as the non-manufacturing research had established. To test the model, the parameters, α and ϕ in equation (2.3) were estimated by taking natural logarithms of both sides of the equation and treating the resulting linear form

$$\ln\,[m(t) / n - m(t)] = \alpha + \phi t, \qquad (3.4),$$

as a regression equation. When the estimated parameters were substituted back into equation (2.3), Mansfield concluded that the calculated values of increase of adopters over time generally provided a good approximation to the actual values. This inter-industry diffusion model was extended to examine intra-firm diffusion rates (Mansfield, 1963) and similar conclusions were reached that the proportion of a new innovation possessed by a firm should also be a logistic function of time.

To examine the factors that affect this diffusion rate, Mansfield proposed that if equation (2.3) holds then ϕ, the rate of diffusion, should vary directly with profitability, π and inversely with size of investment, S. Thus ϕ should be a linear function of π and S. By regressing ϕ on π and S for innovations in four industries, brewery, coal, steel and railroad the coefficients of π and S were found to have the expected signs, the former being positive and the latter negative (Mansfield, 1961; 1968). Thus Mansfield concluded that more profitable innovations and ones requiring smaller investments diffused more rapidly than less profitable ones and the ones requiring larger investments. Mansfield considered four additional factors that might also be important in explaining the differences among rates of diffusion among industries. These were the durability of the equipment to be replaced, the annual growth rate of the industry, time and the phase of the business cycle in which the innovation was introduced. However, none of these factors was statistically significant.

In the case of factors affecting inter-firm diffusion rates and why some firms are faster than others in adopting innovations, Mansfield regressed the diffusion lags of firms, defined as the number of years a firm waits before using the innovation on firm size, expected profitability of the investment in the innovation, the firm's rate of growth, the firm's profit level, the age of the firm's president, a measure of the firm's liquidity and the firm's profit trends. He found only firm size and the profitability of investment to be significant. Similarly, firm size and profitability of innovation proved significant in the case of intra-firm rates of diffusion.

Mansfield's work became a standard for most technology diffusion studies in economics in the 1960s the 1970's including the international collaborative research on the diffusion eight industrial technologies edited by Nabseth and Ray (1974), Romeo's (1975) as well as Globerman's (1975a, 1975b, 1976) diffusion studies in the Canadian context. In a study of the diffusion of the special presses, for example, Hakanson (1974) constructed a mathematical model in which the adoption decision, quantified as the date of first commercial introduction, was the dependent variable, and innovation, company, attitude, profit trend and firm size were independent variables. The innovation variable, interpreted as profitability, was assumed to be the most important independent variable and was calculated as a function of pay-off period. Exploring first the impact of profitability and then the other variables Hakanson reached similar conclusions as Mansfield, that profitablity and firm size were the most significant factors for adopting special presses, though recognizing such company variables as ownership, and date of first information as having some explanatory role to play.

Similarly, Globerman (1975a) in a study of innovation diffusion in the Canadian tool and die industry, fitted a logistic curve and found that his data were well approximated by the logistic curve. For the inter-firm model, Globerman regressed the possession of an innovation on firm size, measured by the total number of employees working for the ith industry; ownership; age of president; level of education of president; and firm R&D. He found firm size and age of president to be significant. Also in the pulp and paper study, Globerman (1976) used date of first adoption as the dependent variable and average length of run on paper machine, firm size, number of machines operated by the firm, number of years the company had been producing paper, age of company president and ownership as independent variables. The results indicated that early adoption was related to firm size and length of run on the paper machine. In particular, the larger the size and the longer the run, the earlier the adoption.

LeHeron's (1973) study is one of the earliest works in industrial geography that focussed on diffusion of industrial technologies. He identified a number of factors that are critical to the spread of best-practice technology which included the nature of intra-and inter-firm development arrangements prevailing during the technology's evolution; the attitude of the recipient industry; the cost of purchasing and installing equipment and technological convergence. According to LeHeron, where no special arrangements between suppliers and users of the technology existed during the development of the technology, the innovation would in all probability be marketed to the industry as a whole. With reference to attitude, LeHeron noted that some industries are receptive to innovations while others are not. An unreceptive industry may stifle an innovation or force out technological developments while a receptive one may forster or allow innovations to thrive. In the case of capital-labour ratios, LeHeron noted that in industries where the cost of capital is low relative to labour costs standards of technological obsolesence are more stringent. On the other hand, where real investment is costly relative to labour, the capital structure of the industry will consist largely of outmoded equipment.

Oakey et al (1982) distinguished between product and process innovations and found that the spread of process innovation, in particular, was accounted for by availability of capital grants to purchase the innovation. In a preliminary study of the rates of diffusion of process technology, namely computerised numerically controlled (CNC) machine tools and the use of micro-processor based controls in 9 industries in the United Kingdom (UK), Edwards and Gibbs (1982) used organisational structure of the firm and establishment size, type of production and R&D activities as variables, to test the hypothesis that

> "larger enterprises will adopt new technologies earlier than smaller enterprises, largely because of economies of scale, continual replacement of equipment, access to greater financial resources and their ability to accept higher risk"

The results indicated that group establishments adopted at a consistently higher rates than individual firms and thus supported the hypothesis. Strong links between R&D and adoption of process innovation were also identified. Firms without formal R&D on site had low rates of adoption. Edward and Gibbs, therefore, concluded that utilization of certain technologies was closely linked to a number of features which influenced the ability of any plant to adopt given innovations.

Thwaites (1983) was concerned with spatial and temporal patterns of diffusion of a number of preselected techniques as part of a larger work on how technological change may condition employment. He analysed data on adoptive behaviour of UK establishments and found that plants in the South-East recorded higher rates of adoption than plants in the Northern region for both process and product innovation. He also found that possession of R&D on site and status of plants were the most important factors, governing the rate of adoption.

To provide more evidence on the adoption and diffusion of technology at the local or plant level, Gibbs and Edwards (1985) attempted to trace the interregional diffusion of a number of technologies, including automatic machine control systems in a number computer-based technologies in nine sectors in the UK Questionnaires were sent 4900 plants of which 1234 responded. The questionnaires were designed to distinguish between adopters and non-adopters after which 130 plants were sampled from both groups and interviewed to explore in greater depth the characteristics of adopting and non-adopting establishments, their approach to technological change and investment as well as reasons for adoption and non-adoption of specific technologies. On the basis of these data, a number of hypotheses were tested mostly by logit analysis. Adoption rates were found to be lower in Development Areas and highest in the South West of the UK To investigate adoptive behaviour it was hypothesised that, in addition to the arguments of Thwaites (1978) and Ewers and Wettman (1980), that technical change may vary systematically between regions and that variations arise because of the nature of enterprise operating in the area. Though industrial structure was not a significant determinant of adoption rates, strong associations were found between corporate status and employment size and access to R&D facilities. In the case of corporate status, the test showed that the lowest-status plants of multi-plant enterprises less frequently adopted the technology while group, regional or divisional headquarters were more highly adoptive. Single plant enterprises were the least adoptive of all establishments. Regarding size, small establishments were low on adoption since large establishments were more likely to obtain investment finance and had the ability to systematically monitor and evaluate technological developments. A strong association was also found between possession of R&D on site and adoption. Adopting firms also had more diverse means of obtaining information, including as a result of internal R&D committment, attendance at exhibitions and contacts with customers and consultants. Further examination of the regional variations of these factors showed that Development Areas did not fare well in all the characteristics that were positively associated with higher adoption rates. Financial barriers and the of governments, for example, were the main causes of non-adoption. Thus, in connection with the low adoption rates in Development areas, Gibbs and Edwards concluded

> "... such areas tend to have lower proportion of 'high tech' industries, larger proportion of branch plants and single-plant enterprises, larger proportion of smaller plants and lower representation of R&D facilities on-site".

A similar work by Rees, Briggs and Hicks (1985) examined the differences in the spread of key computer-based production innovations and their labour impact in the United States (US). Among the specific technologies studied were numerical machine control (NC), computerized numerical control devices (CNC) and computers used for commercial activities. Adoption rates were related to a number of variables, such as industrial sector, organizational type (single and multi-plant), size of plant, age of plant, amount of R&D carried out and locational characteristics of the plant. In the case of organisational structure, they found that larger multi-plant enterprises were more likely to adopt the latest available processes than smaller, single plant companies. Large plants had higher rates of adoption than small plants. An inverse relationship also existed between adoption and age of plant. Older plants were more adoptive than new plants, while plants located in more urbanised areas had higher rates of adoption. On the relationship between R&D and adoption rates, no statistically significant differences in adoption rates were found for five out of the eight technologies studied. For the remaining variables, the association was reasonably significant for only microprocessors and this was because of the creative nature of work to be done on-site before the application of microprocessors.

In another study, Rees, Briggs and Oakey (1986) investigated the spread of selected number of new production technologies related to computerized automation within manufacturing and their impact on existing jobs. By and large, this study was a re-run of Rees, Briggs and Hicks (1985) except the part which dealt with labour impact. When the firms were asked about their adoptive behaviour those that had greater adoption of CNC system indicated that they had shortages of skilled machinists while regions with low incidence of CNC adoption were regions with no skilled labour problem. On production technology, it was found that of the CNC adopters in the east north central region, 8 out of 9 plants concerned did not use assembly line production compared to 3 out of 7 adopters in the west south central region. It was concluded that contrary to the popular notion, CNC adoption was not related to mass production.

To sum up, the diffusion of technological innovation within the manufacturing sector has largely been seen in terms of the adoption behaviour of the manufacturing firm. The decision to adopt is seen as a function of certain characteristics of the innovation, the industry and the firm. The identification of what constitute the elements of these characteristics are dependent on the disciplinary tradition by which the issue is studied. While economists have emphasised such innovation characteristics as profitability and industry/firm characteristic as size, geographers have also emphasised such factors as firm size, possession of R&D facilities on site, organisational/firm structure and location.

Some Criticisms of Conventional Studies

Clearly, these "conventional" studies have uncovered some complex interrelationships of the diffusion pattern. At the same time, in both geography and economics, a number of criticisms have been made against them. In economics, the epidemic analogy underlying the Mansfield model used in most studies has been seriously questioned by researchers interested in mathematical modelling of the diffusion process. In particular, Davies (1979) has criticised the logistic model on the grounds that it ignores decision-making by firms under uncertainty. Claiming that he was adopting a behavioural approach to diffusion studies, Davies identified two types of innovations- an A-type, which is simple, less costly and diffuses rapidly and a B-type which is complex, more costly and takes a long time to diffuse. Davies postulated that the potential adopters of an innovation will adopt when their assessment of the profitability of adoption is sufficiently favourable to suggest that they will be able to recoup their initial capital outlay in an acceptable time. For three main reasons, namely ability to acquire information, attitudes to risk, and broad goals, neither the profitability of the innovation to all firms nor the behaviour of all firms is identical.

Davies considered a number of factors that would be responsible for these differences. However due to difficulties in quantifying most of them and for reasons such as the ability to achieve economies of large scale production, ability to underwrite risk and the likelihood of having expertise for successful adoption, Davies singled out firm size to be the primary determinant for these differences. Assuming that the probability of adoption will vary across firm size, measured by output, and assuming a log normal distribution for firm size, Davies derived an aggregate diffusion curve, which conforms to a positively skewed cumulative log-normal curve if the innovation is of the A-type and a symmetrical cumulative normal curve if the innovation is of the B-type. However, for all innovations, the curve will be the usual logistic S-shaped curve.

Metcalfe (1981), Freeman (1982) and Stoneman (1976, 1983) argued that conventional diffusion models neglect the supply side of the diffusion process. In particular, Metcalfe noted that as a result of the neglect of the supply side of the diffusion process, important interactions between the growth of demand and the growth of productive potential are ignored. In addition, the standard model is static and assumes that a given innovation takes place in an unchanging environment. With reference to the importance of profitability factor in explaining adoptive behaviour, Metcalfe poses a rhetorical question:

> the emphasis in diffusion research upon the profitability of using an innovation as seen by potential adopters but what of profitability as perceived by the producers of the innovation?

To address this situation, Metcalfe developed a model of diffusion jointly determined by the supply of the innovation, whose demand depends upon a changing price, and the profitability of adoption.

Even though the work of Davies, Stoneman and Metcalfe introduced new dimensions into diffusion modelling, the benefits of their efforts were predated by concerns raised about the validity of studies in mathematical diffusion modelling. In particular Gold, Rosseger and Pierce (1970) argued that the complexity of the diffusion process is such that it is impossible to build mathematical models to explain it. In addition, the basis of all the mathematical models is the assumption that a population of potential adopters for any given innovation can be readily identified. Unfortunately should there be any change in the innovation during the diffusion cycle, as Rosenberg (1976) has pointed out, this population cannot be identified and the whole construct of the mathematical models crumbles. Clearly, neither Davies, Metcalfe nor Stoneman addressed these issues. Indeed, Davies (1979 p. 19) made an attempt to dismiss Gold et al's (1970) criticism; as we have already seen this attempt was not successful since he was not able to quantify the behavioural variables he identified in his model. As a matter of fact, the inability to quantify many of the important variables that are identified is not only characteristic of Davies' work but also with most of the work that adopt the mathematical approach. Thus in Mansfield's (1968) interfirm model as well as Globerman's (1975a, 1976) studies four out of the seven variables had to be dummy coded. In addition, the need to increase sample size to justify the underlying assumptions of the regression technique has resulted in situation where the date of adoption by so-called potential adopters had often been arbitrarily assumed (Nabseth, 1973; Nabseth and Ray, 1974; Hakanson, 1974; Globerman, 1975a).

Other criticisms have focussed on the conceptualisation of the diffusion process and the factors that have been emphasised as important determinants of the diffusion process. With respect to the factors, most of the crticisms have centered around the claim that profitability is the most important determinant of adoptive behaviour. [2] Gold (1970) contended that competition rather than profitability is the most important factor for adoption of innovation. Thomas and LeHeron (1975) argued that profitability of firms did not depend entirely on the technological rank or obsolescence of capital equipment. Rather management quality, organizational structure, scale economies, favourable location, relative factor prices, control over prices, management attitudes were all

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2. The controversy about profitabilty as the most important explanatory factor of diffusion is not only limited to the manufacturing sector. Diffusion researchers in sociology raised the issue soon after Griliches' (1957) study. For example, Brandner and Straus (1959) argued that emphasis on profitability as the most important factor in the diffusion process renders factors as socioeconomic status, individual and group values as mere auxilaries. From a study of diffusion of hybrid sorghum in the northeastern and southwestern parts of Kansas, Brandner and Straus concluded that familiarity or congruity accounted for the higher rate of acceptance. Similarly, Havens and Rogers (1961) argued that what really determined the rate of adoption of an innovation is the adopter's perception of profitability and not objective profitability.

examples of factors which could influence diffusion. They called for more studies that would probe the relationship between profitability and adoption rates, investigate the effect of "friction of distance" on the rate of diffusion, and look at manufacturing industries and firms located in specific countries, regions and cities to provide more insight into the processes of firm growth and decline in different geographical contexts.

David (1975) also argued that the gradual adoption or diffusion of innovation is not simply a temporary disequilibrium phenomenon reflecting differences in the alacrity with which different enterpreneurs respond to a uniform economic stimulus, the opportunity for each to make a profit by cutting costs. Instead, diffusion is portrayed as the reflection of a changing distribution of production among different techniques chosen rationally by a heterogenous population of firms, a population for which it could not be said that the latest method that has become available at any moment necessarily constituted the best technique. On the basis of this argument, David suggested that a deeper understanding of the conditions affecting the speed and ultimate diffusion of an innovation is to be obtained only by explicitly analyzing the specific choice of technique problem which its advent would have presented to the potential adopters. Using mechanisation of reaping in the American Mid-West as a case, David established that the adoption of mechanical reapers did not proceed instantaneously but only as farm size increased and the cost of reapers declined relative to wage rates.[3]

On the conceptual aspect, Gold (1981) examined diffusion literature over a period of 20-25 years and observed that diffusion research reports had tended to mislead government officials and had been harmful to industrial management well. Gold attributed the cause of this situation to the tendency for diffusion researchers to generalize from findings based on inadequate sample size and from studies that are not deep enough to reach the roots of the complex considerations underlying the actual decisions reflected by diffusion rates. On the premise that technological diffusion rates in

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3. Even though David's work is not in manufacturing, it is included here because of its relevance to the framework we will develop.

the United States are determined by managerial decisions at the individual firm level, Gold suggested that diffusion research should focus on five areas, namely identification of the effects of successive improvements on the technological capabilities and limitations of particular innovations; estimation of resulting changes in the number and characteristics of active adoption prospects; exploration of the evaluation processes of individual firms which underlie adoption decisions; analysis of economic and social effects of increasing diffusion on the growth and competitive strength of the industry, communities and regions, governments agencies, trade unions and consumers; evaluating explaining the evaluation processes of individual firms which underlie adoption decisions.

To pursue this new focus Gold and his colleagues (1984) constructed first, a detailed stage-by-stage decision processes to show among other things that decisions about technological innovations fit into the general decision processes. Second, they placed these processes in a decision-making model which consists of four main components, namely firms' predecision environment, characteristics of the innovation, how firms make evaluations, and how firms combine evaluation results into a decision. The most important elements in the predecision environment are urgency of needs, the nature of the needs and the existence of any marked managerial preferences among such alternatives. Innovation characteristics include the source and nature of the innovation, as well as the expected risks and benefits, while the firm's evaluation and decision procedures include how the firm weighs risks and uncertainties, whether or not the firm relies on engineers for technological decisions, and the extent of the firm's orientation to the market. The major point of these criticisms of economic studies appears to be summed up by Dosi (1984 p. 287):

> "the 'logistic' approaches to technological diffusion represent a major achievement in that they establish a rather general stylised fact of the process. However, they do not explain it. They provide an ex-post rationalisation on the conditioned probability of a non-adopter to become an adopter of an innovation. In that they show exactly the same descriptive usefulness as well as the limitations of the epidemic curves (or for that matter, probability models) to which they are formally similar: they can show the pattern of diffusion of say cholera and they can also relate it to some broad environmental factors such as conditions of hygiene of a town... but they cannot explain why some people get it and others do not.."

Turning to geography, similar criticisms of conventional diffusion studies can be found in the works by Thomas (1985) and McArthur (1987). Thomas (1985) attributed the little understanding of the relationship between technological change and regional development to inadequate conceptualisation by previous studies, and called for disaggregated studies that would get into the micro-foundation of the process of technological change within a multi-disciplinary context. Thomas considered two main factors in his new framework, the *regional factor*, and the *innovative factor*. He argued that the regional factor should be broadened to include such elements as the region's population, industries, transportation, economic and social infrastructure, government policies, natural resources etc. With respect to the innovative factor Thomas considered innovation as a non-routine decision which needs to be understood differently from day-to-day routine decisions. The behaviour of the firm faced with a non-routine decision regarding the future, according to Thomas, is influenced by the distilled memory of the history of each member firm. Firms therefore attempt to synthesize the past and present flow of information as generated from internal and external sources of the firm's decison environment. Thomas suggested three notions as foundation blocks for a new framework for understanding the behaviour of a firm facing non-routine decisions, such as innovative activities. The first is the firm's *decision or selection environment*, which is determined partly by conditions within the firm which influence its behaviour, and partly by the characteristics and behaviour of other firms in the firm's industry and such external conditions as product demand, factor supply and factors influencing information flow. The second is the firms *organizational routine*, which will determine whether the firm is capable of dealing with unprecedented situations or changes in the decision environment and which also determines the firm's effectiveness in adapting or replacing existing organizational routines. The third is *organizational search* , which is initiated by the firm to look for and evaluate activities which might lead to the modification or dramatic change or replacement of current routines.

McArthur's (1987) study of colour scanners in the UK aimed at examining the basis of some of the conventional notions on which the shape of the diffusion curve and the factors explaining the diffusion curve are based, with particular reference to the concept of potential adopters and the factor of firm size. Starting in a conventional way, McArthur plotted the number of scanner machines that have been adopted and obtained a diffusion curve which bore almost all the features and subsequent interpretations of the conventional diffusion curve. For example, the curve indicated that large establishments accounted for 85 per cent of the early adoptions the percentage dropping to 10 per cent later on. However, when technical changes in the scanner over the diffusion process came to be examined, it was revealed that the dominance of of large firms in the early stage of the diffusion process was due to the limited applicability of the scanner, which was only suitable for large firms. When those limitations were removed through technical changes the advantage began to swing back towards small establishments. These technical changes also revealed a new range of users of scanners who could not have been identified at least easily at the beginning of the diffusion process. Thus McArthur argued that establishment size is not wholly exogenous to the diffusion process and that the critical factor seemed to be the degree of specialisation of the establishment. He also gave more evidence to support how difficult it is to define a population of potential adopters for some technologies.

From the point of view of geographic research on diffusion of industrial technology the work of Thomas (1985), Gold (1981, 1984) and McArthur (1987) as well as David (1975) provide significant contributions. First, both Thomas and Gold, and to a lesser degree David, explicitly introduce the decision-making process as part of the diffusion process. This means that in order to understand the diffusion process, it is important to understand the decision-making process that led to the specific choice of the technology. That is, in the final analysis, the pattern of diffusion that emerges in a space is the direct outcome individual corporate choice decisions. An understanding of what decisions were made, where, when and why they were made therefore holds the key to the understanding course of the diffusion process. Second, McArthur's work shows that technical changes in innovation during the course of the diffusion process itself can affect the adoptive behaviour of firms. This point not only raises implications for consideration of R&D processes as part of diffusion studies but also for consideration of a broader technological context. Indeed, research work on innovations inside and outside geography has shown that development of innovations involve a network of co-operation between both users and suppliers. In particular, Von Hippel (1977, 1978, 1988) identified three such sources of innovation: users, manufacturers and suppliers and provided evidence to show that the nature of the source do have implications for the spread of the innovation. Similarly, a number of interesting studies of the development of industrial technologies in Hakanson (1987) show a considerable degree of collaborative work in the course of development of innovations. Such collaborative efforts which can affect the spread of the innovation, cannot be captured if the R&D processes are not considered as part of the diffusion process.

In addition to these two ommisions pointed out by Thomas, Gold and McArthur, conventional studies of industrial technology diffusion in geography have also missed out on other elements that are relevant to understanding the diffusion process. Dosi and Orsenigo (1988), for example, have argued that within a given industrial structure there are such factors as technological assymetries, varieties, as well as behaviour and organisational diversities, all of which affect innovativeness of firms within the industry. Similarly, Pavitt (1984a) has attempted a classification of industry structure into supplier-dominated, scale-intensive, specialised supplier and science-based sectors and has shown that these structures affect the pattern of technological diffusion. Apart from these, the effectiveness of factors like firm size , possession of R&D on site; organisational structure, location may depend on the nature of the industry, the characteristic of the dominant technology and the general forces that affect changes in these technologies. For example, it is generally known that in most process industries two types of technological developments exist: process development and developments in operations which usually results in machinery (OECD, 1988). While most process developments are generated by the firms in the industry most operational developments are undertaken by firms outside the industry. As a result possession of R&D facilities, for example, will ot be important to the adoption of a new machinery as it will be for a new process technology. In this case, a statistical test showing a non-significant association will be misleading if the result is interpreted outside the context of the industry and with particular reference to the type of technology. This also means that the role of suppliers, for example , will be expected to be more important if the dominant technology is operational in contrast to process.

Finally, in spite of the growing internationalisation of firms, global competition and increasing interdependence, technology diffusion studies in the manufacturing sector conducted by geographers have failed to extend the analysis of their spatial scale beyond national boundaries. In virtually all cases these studies have interpreted countries as closed systems. That is, these studies have focussed only on diffusion patterns in a specific nation or region and the diffusion pattern has been explained solely in terms of the internal characteristics of nations and regions. As Porter (1985, 1988) has forcefully argued, there is a strong technological dimension to competitive strategy and whether manufacturing firms pursue a focus, cost leadership or differentiation strategy, the vehicle for implementing the particular choice of competitive strategy usually has a strong technological component. Besides, in export-oriented industries national firms do not only compete among themselves within their domestic markets but with firms from other nations on the international market. Also increasing interdependence has led to situations where developments in one country directly affect another. For these reasons examination of technology diffusion process without consideration of wider spatial contexts can overlook some of the relevant explanatory factors.

From the foregoing discussion, this thesis agrees with Dosi (1984) and Thomas (1985) that while the conventional approach of diffusion studies have performed well in describing patterns that exist, it has been less useful in accounting for the processes that produced those patterns as a result of inadequate conceptualisation. The thrust of this thesis is that the technology diffusion pattern that can be observed at any place and at any time is the outcome of individual corporate technology decisions. These choices are made within broader contexts of industrial, technological, spatial and managerial environments. To understand the factors that explain the diffusion process it is therefore important to understand how and why firms choose particular technologies for particular locations at particular times and the contexts within the decisions are made. This thesis recognises that the technology diffusion can best be studied by an explicit incorporation of technology choice and the environments in which these choices are made.

The Nature of Corporate Decision-making

Within the general literature on organisational behaviour important distinctions have been made between the nature of decisions and the decision-making process at individual, group or organizational and interoganizational levels. Among the most popular typologies of decisions within the organizational sector are Simon's (1947, 1965) programmed and non-programmed decisons and Ansoff's (1965) operating, strategic and administrative decisions. Programmed decisions and operating decisions are routined and therefore have predetermined outcomes while non-programmed, strategic and some administrative decisions are not.

The general approach that has been used in studying how each of these typologies of decisions are made is the open systems theory (Fig. 2.1). Usually, the system is viewed as consisting of four component parts- input, process, output and the environment (Easton, 1965). With reference to the firm sector Bridge and Dodds (1975), consider inputs as problems which have to be solved; process as the management process and output as the solution to the problem (Fig. 2.2). Within this framework research work has concentrated on four main issues, namely modelling the procedures by which a decision is made; developing techniques that will help the decision maker to make the desired decisions; developing models that explain or predict the behaviour of the decision-maker and explaining the forces that influence the decision-making process. For the purpose of this thesis, we will focus on the first, third and the fourth issues.

Studies which focus on the procedures of decision-making usually view decision making as an on-going process consisting of clusters of events, which generally begin with identification of some problem and terminate temporarily in the solution of the problem. Each cluster constitutes a stage in the process and is sequentially executed. The number of stages and their terminologies are

FIG. 2.1 : THE GENERAL FRAMEWORK OF DECISION MAKING STUDIES

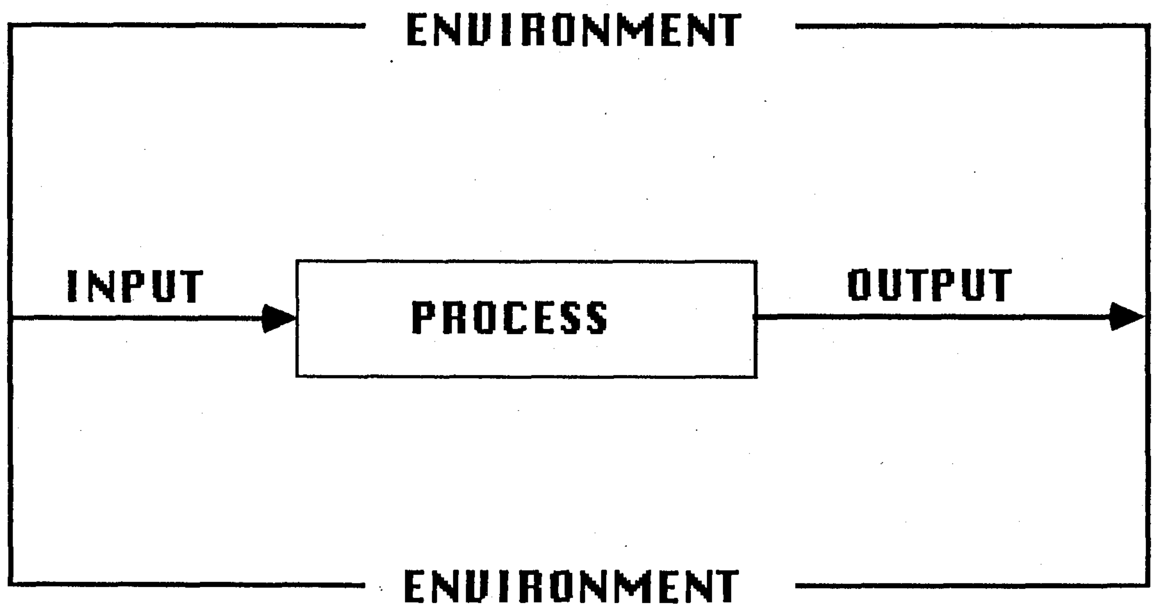
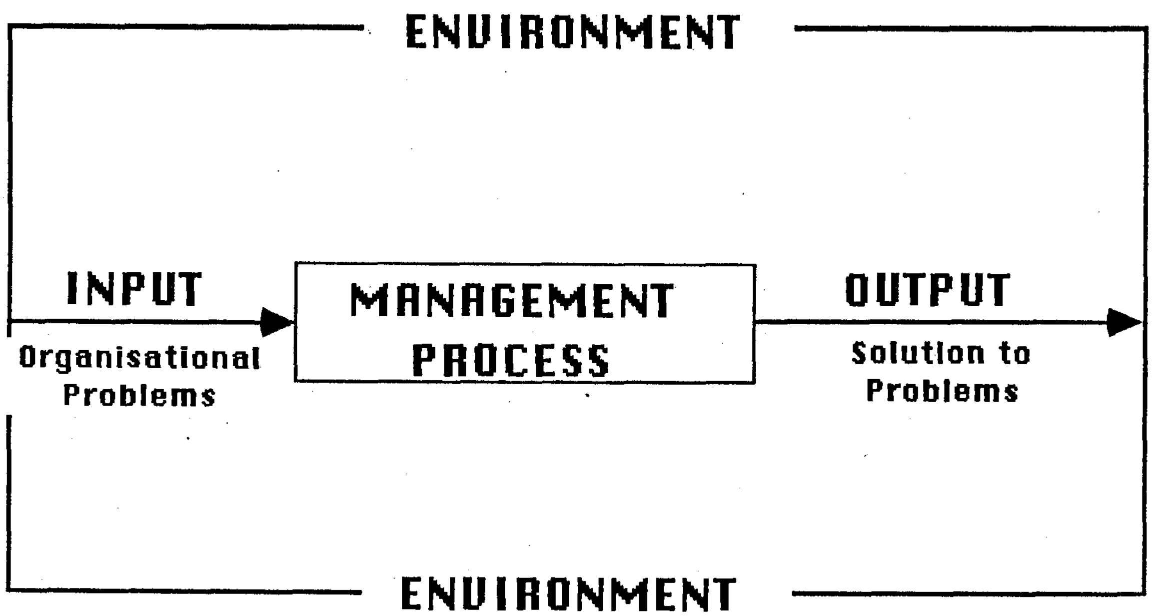


FIG. 2.2: A GENERAL FRAMEWORK OF CORPORATE DECISION MAKING



Adapted from Bridge and Dodds (1975 p.4) determined by the model builder. Thus Simon (1960) had three stages: finding occasion for making a decision; finding possible courses of action and choosing among courses of action. Witte (1972) has information gathering, development of alternatives, evaluation of alternatives and choice. Schrenk (1969) has problem recognition, problem diagnosis and action selection. Others include developing a set of criteria, posing criteria questions, scaling the responses, choosing alternatives (Frederickson, 1971); recognising and defining the need, the search for alternative, evaluation of alternatives, decision (Bridge and Dodds, 1975) and setting managerial objectives, screening for alternatives, comparing and evaluating alternatives, choice, implementing the decision, follow-up and control (Harrison, 1981). The approaches suggested by Gold (1981) and Thomas (1985) are thus within this tradition.

The issue that has attracted most attention and discussion is how to explain and predict the behaviour of the decision-maker. The attraction of this issue to many disciplines has resulted in the development of several decision-making models, some of which are very difficult to differentiate (see Miller, 1982; Harrison, 1981; McGrew and Wilson, 1982; Hammond, McClelland and Mumpower, 1980). In spite of the different classifications, and with particular reference to the firm sector, two main models are dominant. These are the rational economic model and the behavioural model. Originating from classical economics and the work of von Nuemann and Morgenstern (1953), the central feature of the rational model is the rational economic man who has all the knowledge about all alternative courses of action and their outcomes and therefore chooses the course of action that maximises his gains or minimises his cost.

In contrast, behavioural models reject the rational and maximising behaviour of the economic man on the grounds that they are not realistic to the decision-making behaviour. In place of economic man, behavioural models posit the administrative man who is rationally bounded and therefore satisfices instead of maximises (Simon, 1947, 1955; Edwards, 1954, 1961, Leibenstein, 1966, 1969) Decision problems, behavioural models assert, are so complex that decision-makers do not have knowledge about all the alternative courses of action at their disposal before they make a decision (Cyert and March, 1963). The result is that decision makers consider only a limited set of alternatives that bring incremental gains to organisational goals (Lindbolm, 1959; Etzioni, 1967) and the search for alternatives usually terminates when a particular course of action meets organizational objectives (Cyert and March, 1963). Harrison (1981) has further classified behavioural models into three, according to their objectives. The organisational model typified by the work of Simon, Cyert and March is concerned with outcomes that benefit the firm at least in the short run. The political model of Lindbolm and Etzioni aims toward an outcome acceptable to external elements of the firm while the process model of Mintzberg, (1973) is oriented toward long-term results. Supporters of the rational model have reacted to these criticisms from the behaviourist, concentrating mainly on what maximising behaviour means and the debate is still going on (see for example Malchup, 1957; Haring and Smith, 1959; Friedman, 1962; Koplin, 1963; McGuire, 1964; Rostow, 1967; Jorgensen and Siebert, 1968; Herendeen, 1974; Simon, 1978, 1979; Harrison, 1981; Rosenberg, 1982; Cyert and Simon, 1983).

Behaviour of decision-makers is not the only controversy in decision-making studies. Within the discussion on the forces that influence the decision making process, Miller (1984) points out that great controversy also exists over organization-environment interaction. On one hand is the environmental determinist view that organisational action rests on predetermined environment leaving very little room for managerial discretion (Aldrich, 1979). On the hand is the view that organisations are proactive and that managers choose environments and plot strategies to fit them (Child, 1972; Lawrence and Lorsch, 1967). A third view, put forward by Miles (1980) , holds that managers persist in learning and adapting to environmental constraints and contingencies.

This controversy aside, there is a general agreement that a firm's environment influences its decisions. This influence exerts itself in uncertainty, or states of nature (Braverman, 1980), which is generated by economic, political, social, physical and technical or technological forces (Elbing, 1978; Harrison, 1981). The degree of the uncertainty depends on the nature of environmental change and in order to understand the firm-environment interaction, some attempts have been made to model these changes. Two main types of changes have been identified: direct change, which are changes among those parts of the environment with which the firm has direct links with and indirect change or causal textures (Emery and Trist, 1965) which are changes among factors that lie beyond the direct control of the firm. The main dimensions of direct environmental change are simple-complex, static-dynamic (Duncan, 1972) and scarcity-munificence (Staw and Szwajkowski, 1975) while placid/random, placid/clustered, disturbed/reactive and turbulent are the main forms of causal textures (Emery and Trist, 1965; Harrison, 1981; Miller, 1984). In addition to these factors various theories of organizational behaviour have identified factors internal to the firm which affect decision-making. Among these factors are managerial perception, individual and group value systems (Jacob et al, 1962; Guth and Taguiri, 1965; Elbing and Elbing, 1967; England, 1967, Lusk and Oliver, 1974; Elbing, 1978; Harrison, 1981) , group structure, group size, communication styles and managerial styles (Elbing, 1978; Harrison, 1981; Gilligan, Neale and Murray, 1983).

The Nature of Technology Choice

Existing empirical work focusing on technology choice, most of which has been done by economists, has largely reflected the main trends in this decision making literature, particularly, the contention between the rational economic model and the satisficing behavioural models. Until about late 1960s, the rational economic man model dominated neoclassical theoretical formulations about technology choice. As would be expected, these formulation assumed a world of homogeneous product with many small competitive firms, an infinite number of techniques of production to choose from, and managers whose decisions are solely motivated by economic objectives. Given these assumptions, it was postulated that if all information were available and if all labour and capital cost were known, then firms would choose the technology that combined capital and labour in such a way that production cost will be minimum. If new technologies are considered more efficient than old ones then, firms would choose the most modern technology. Moreover, since all managers have one single objective- to minimise production cost- it also follows that firms in the same country and producing the same product would, in general, choose the same technology. However, since factor costs vary by country, the optimal ratio of labour to capital will vary by country. The choice of technology in this case will also vary by country. The main factor affecting technology choice in this framework, therefore, is profitability. At the turn of the 1960s , as a result of the general reaction to the rational model, several empirical discrepancies began to be observed about the theory. In particular, it was observed that firms within the same industry were using different technologies to produce the same products. This observation led to a series of studies among which were Yeoman's (1968); Wells Jr. (1973); Keddie (1976); LeCraw (1976) and Amsalem (1983).[4]

Yeoman (1968) examined the kind of changes in production methods made by US-based multinational enterprises in response to differences in factor costs and the reasons for the changes. Yeoman argued that the conventional economic theory of technology choice was inadequate. In particular, he questioned the assumption of profit-maximising behaviour with perfect knowledge and perfect competition on two grounds: first, whether a wide enough range of technologies is actually available to allow the manager to use the various mixes of capital and labour and second, whether factors of production are homogenous and comparable across countries. Yeoman studied adaptive behaviour of 13 multinational firms in three industries, pharmaceuticals, farm machinery and construction, mining and household appliances. He found that the firms responded to differences in relative factor costs in different ways. In the pharmaceutical and machinery industries there was little inclination for adjustment of processes to local conditions. In the appliances sector there was much less response to factor price changes among firms engaged in heavy manufacturing than those in light manufacturing. Yeoman identified cross-elasticity of demand faced by the individual firm and the relative importance of manufacturing cost to total cost expended in bringing the product to the market as the two most important factors explaining the technology choice behaviour of the firms in his sample. With respect to the first, Yeoman noted that the countries with cheap

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4. Abriged versions of these studies can be found in Stobaugh and Wells, Jr (1984 pp 1-127)

labour were in most cases the very ones in which the firms had been granted monopoly positions. Under such conditions, production cross-elasticities are extremely low; as a result, the incentives to identify the least-cost production process are not great. In the case of the second factor, Yeoman observed that where manufacturing labour and depreciation costs constituted a small fraction of the selling price in the U.S interest in developing new production processes for foreign plants was slight. As the fraction increased, the pressure for factor substitution in overseas facilities increased. Since the relative importance of manufacturing labour and depreciation cost to total cost varied across the 13 firms in the sample, the differences influenced the firms' propensity to adjust their production processes as they built manufacturing facilities abroad.

Wells Jr (1973) probed the complex factors that influence managers in their choices of technologies in 43 industrial plants drawn from six industries in Indonesia. The industries were plastic sandals, cigarretes, bottling, bicycle and betjak tires, flashlight batteries and woven bags. Dividing the technologies in these industries into capital-intensive, intermediate and labour-intensive, Wells did a preliminary investigation of the choice of technologies from these broad classes and found that the behaviour of managers were not consistent with the usual assumptions of economic man model. In particular, he expected that if factor costs were the principal determinants of technology choices, then engineering data should support the choices by showing that capital-intensive technology was suitable for the foreign firms in the study and the domestic firms with subsidies. Instead, he saw that at any reasonable set of capital costs that firms faced, the choice of capital-intensive technologies required an investment per worker that was far beyond that would be consistent with actual wages paid by firms. Wells found that managers' choice of technology appeared to be influenced by two objectives which were in conflict particularly in low-wage countries. The first was the "economic man" objective which led to the choice of labour-intensive technologies while the second was the 'engineering man' objective which led to the choice of capital-intensive technologies. When price competition was the rule, the economic man objective prevailed. When the firm had a monopolistic advantage, the engineering man objective prevailed. In addition, Wells found that the capital-intensive technologies provided some sort of insurance against risk and uncertainty. Thus Wells concluded:

> "The business manager probably does not behave solely as an "economic man". Economics puts a constraint on the manager's behaviour but the manager may also have a competing objective which causes him to function as what could be described as an "engineering man". For some reasons managers do not take a narrow profit-maximising view..."

The objective of Keddie's (1976) study, also in Indonesia, was to test two hypotheses concerning the behaviour of firms regarding the choice of technology. The hypotheses were:

1. The primary concern of firms in adopting technologies is to secure a premium quality or other objective product advantage.
2. This concern is a response to the economic opportunities and risks generated by product differentiation and heterogeneity, representing an economically motivated pursuit of objective product advantage.

Executives drawn from nine manufacturing and two construction industries, both foreign and domestic, were asked why they had adopted the technologies they used as opposed to alternatives. The technologies were classified as low-cost and high-cost investments while the reasons for adoption were also categorised as quality, labour-related problems of maintaining output, machinery-related problems of maintaining output and economy. Responses were classified into two: whether factors were first-mentioned and whether they were mentioned in conjunction with others. The results showed that product advantage was of most concern. Of 46 technology choice decisions in the manufacturing sector, 57 per cent first mentioned product advantage compared to nine per cent, seven per cent and 28 per cent for labour-related, machinery-related and economy respectively. Similarly, 60 per cent of 43 decisions involving plurality of reasons mentioned quality as against seven per cent for labour and machinery-related and 26 per cent for economy. In construction, 44 per cent of the nine technology choice decisions made first mentioned quality, 33 per cent labour-related and 22 per cent machinery-related. The economy factor was not mentioned. In the low-cost investment, the economy factor accounted for as many decisions as product advantage. Evidence for the second hypothesis was uneven. Indeed cost minimising behaviour was not dominant at all.

Lecraw's (1976) study was based on Simon's satisficing concept, Leibensteins's theory of X-Inefficiency and McCain's theoretical constructs of low profit. The theory of X-Inefficiency formulated by Leibenstein (1966) postulated the idea that due to imperfect information, lack of control and incomplete contracts, there can be "inert areas" within a firm that permit individuals to behave in sub-optimal, non-maximising ways, given the goals of the firms' owners. Lecraw tried to find empirical evidence to this situation using Thailand as a case study. He estimated a set production functions for 12 industries in Thailand and compared them with the actual technologies chosen by the firms for their efficiencies. Firms showed both technical and price inefficiencies so Lecraw turned his attention to examine what led those firms to the inappropriate technology choices. Among the factors Lecraw found were risk, level of competition and experience. Perceived risks, including risk of technological failure and unacceptable output quality, had a strong influence on choice. Also with increases in competitive pressure, measured by the number of firms in the industry, firms tended to choose more appropriate technologies in their new investments. Finally, firms whose managers had experience in operating in low-wage countries tended to use more appropriate technologies than the others who did not have such experience. Thus Lecraw concluded:

> Clearly, the choice of technology in low-wage countries depends significantly on factors beyond the relative costs of capital and labour..

Amsalem (1983) also provided some more evidence on the nature of technology choice. The objective of his study was to answer a number of questions which were still controversial regarding the technology choice in developing countries. Among these were: Is there a range of technologies available for the production of a good? If so, do these alternative technologies use the factors of production different enough to make the choice between them a significant issue? What is the role played by production cost minimisation in technology choice, assuming firms face a range of alternative technologies that employs the factors of production in significant different proportions? Are there other considerations besides or in lieu of production cost minimisation that influence technology choice? To answer these questions, Amsalem studied technology choices made by 28 firms in the textiles and pulp and and paper industries in Columbia, Brazil, Indonesia and the Philippines. With reference to the existence of alternative technologies, Amsalem found that even though there existed a number of such alternatives, the scope was limited rather than infinite, as assumed by the neo-classical economic theory of choice. On production cost minimisation, Amsalem developed an index of technology choice relative to the technology that minimises production cost in the US and compared the values of this index different processing steps. In textiles, chosen technologies were found to be labour-intensive more than the optimal for developed countries which indicated that some adaptation had taken place. In the pulp and paper industry very limited adaptation was found. Besides, as scale of operation increased, adaptation decreased rapidly. Factor price distortions were also found to be very limited in the industry due to the limited emphasis on production cost minimisation.

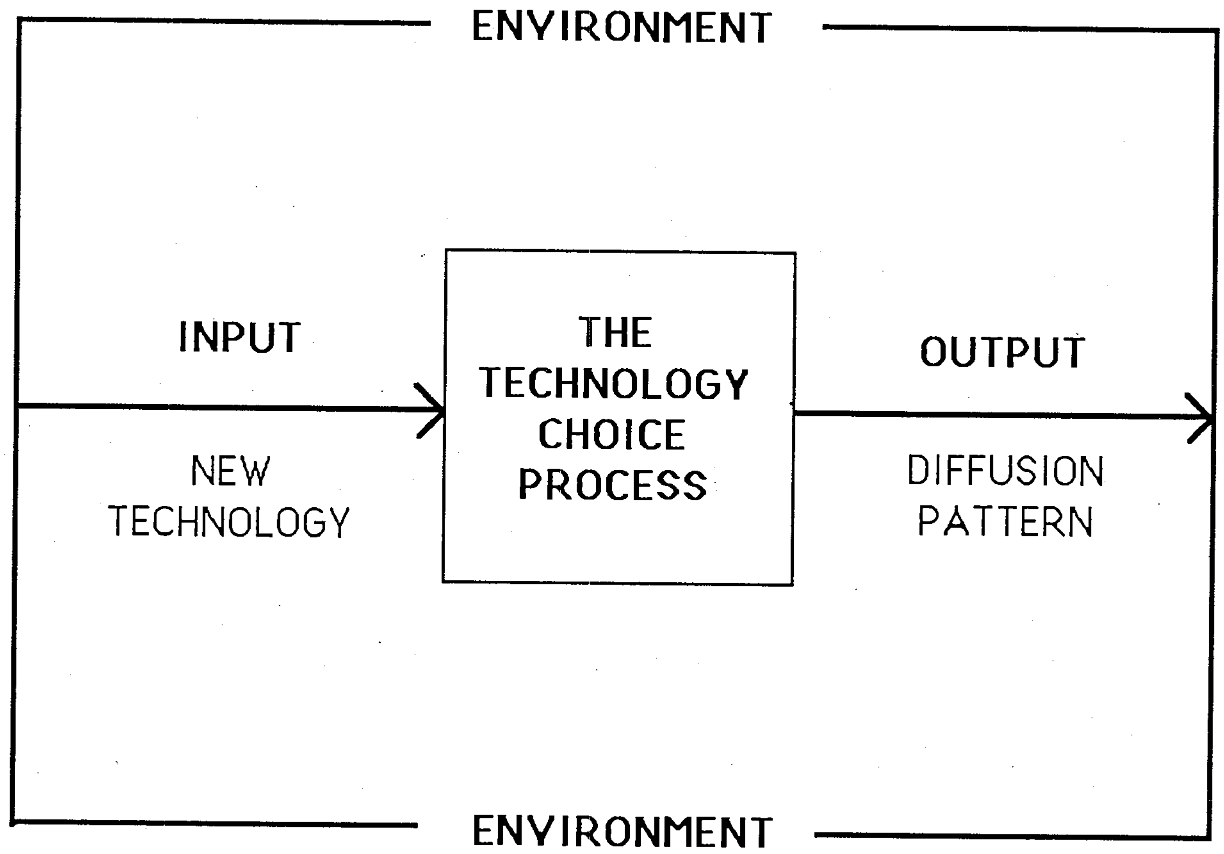
Since the technologies chosen were in most cases not the ones that would yield the lowest production cost to the firm, Amsalem considered other factors, by studying the actual decision-making processes that led to the choice of the technologies. He found that firms based their analyses on much more limited information, due to high cost of information flow rather than imperfections of information flow. In the pulp and paper industry, for example, it was found that the need to adapt the technologies to the characteristics of the raw material of each production unit meant that the technologies had to be custom-made. The high cost associated with each of these technologies automatically dictactes that the number of alternatives to be considered be kept to the minimum. Amsalem also identified risk factors as important determinants of technology choice, particularly risks associated with the use of different factors of production, risk associated with technical failure, political and business situation, labour strikes, unrest and human errors in operation as well as risks associated with deviation from industry leaders. Firm strategy of product differentiation was also found to be an important factor for technology choice. Firms that differentiated their products on the basis of quality chose more capital-intensive technologies while firms that produce on short notice chose labour intensive technologies. Finally, government policy such as tax incentves to attract investments or encourage relocation of firms did affect the choice of technology.

From this review, *technology choice* is considered as an investment decision-making process (Amsalem, 1983) that results in the adoption or non-adoption of a particular technology instead of some other technology by a manufacturing firm/ plant. The effect of the various technology choices by firms in a given space will after a certain time period, define a distribution of all locations where the technology is being used, which will constitute the diffusion pattern. If *diffusion of technology* is conceptualised as consisting of three main components: *input*, *process* and *output* then adopting the open systems approach, the input refers to the new technology or innovation, the process *technology choice* and the output the *diffusion pattern* (Fig. 2.3). In terms of corporate decision-making, technology choice is a non-programmed decision (Thomas, 1985; Simon, 1960). In systems language it can best be considered as open in scope. In approach it is behavioural; it focusses directly on the how and why of the question of choice and it is affected by a number of factors which can best be explained within the appropriate contexts of the within which those choices are made. The nature of these contexts are considered in the next section.

The Context of Technology Choice

The idea that technology choice needs to be studied within the appropriate context stems from the fact that manufacturing firms operate within broader environment. The concept of 'corporate environments' is complex and dynamic and since elements of a firm's environment are interrelated any classification of environments is, to some extent, arbitrary. At the same time, the justification for classifying the corporate environments rests on providing analytical perspective. For the purpose of this thesis, this context or environment is disagregated into four main parts,

FIG. 2.3: THE TECHNOLOGY DIFFUSION PROCESS

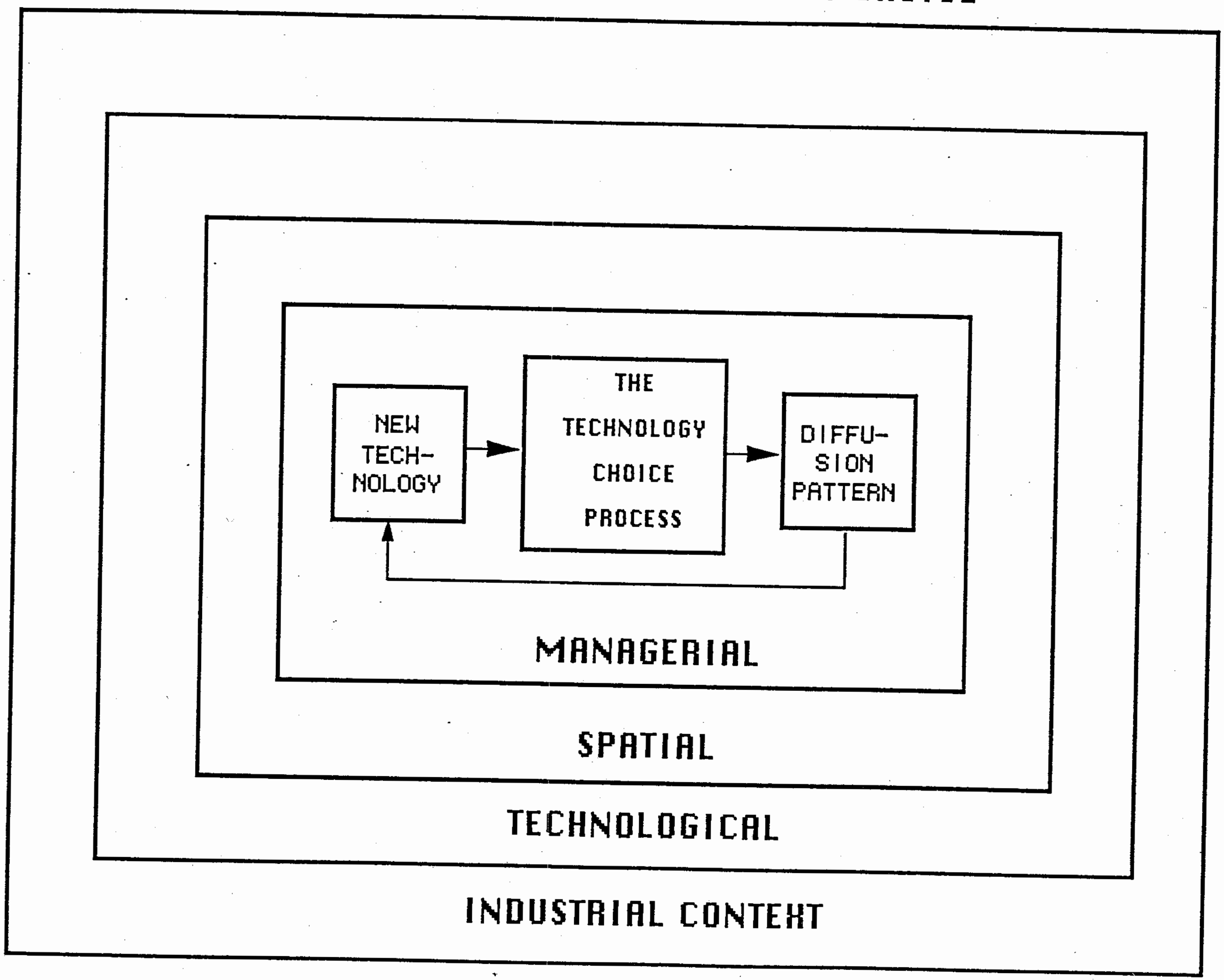


namely, the industrial context, the technological context, the spatial context, and the managerial context (Fig. 2.4).

The Industrial Context

In the first instance the nature of technology choice will vary according to the industrial context, by which is meant the basic organisational, demand, supply and market characteristics of the industry, in which the firm is operating, and their implications for technological change in the industry. Technologies within the manufacturing sector tend to have strong industrial focus. While ocassionally there may be spill-overs to other industries, even the particular role such 'general' technologies may play within a given industry tend to be determined by the characteristics of the industry's production function. Some industries are by the nature of production technologies and production function, labour-intensive, while others are capital-intensive. In labour-intensive industries, as LeHeron (1973) has indicated, the rules or standards of technological obsolesence will be more stringent than in capital-intensive industries. As a result, the rate of R&D activities can be expected to be slower than in capital-intensive industries. For this reason too, it can be expected that the need to make decisions about new technologies may not arise as frequently in labour-intensive industries as in capital-intensive industries. However, even this observation has to be qualified since industries tend to differ within such broad classifications as labour-intensive and capital-intensive. In mature capital-intensive industries, such as, printing and publishing and paper, for example, there is generally slow growth of R&D activities and, for that matter, product innovations as a result of the high cost of capital. In such industries, decisions to adopt new technologies will proceed slowly and with extreme caution. In addition, in labour-intensive industries possibilities for substituting labour with technological developments are much higher than in a capital-intensive industry. In this case the need to substitute labour with technology will be high when labour conditions and cost in relation to the total production cost begin to rise. This also means that the choice of a new technology under such circumstances will be rapid.

FIG. 2.4 THE CONTEXT OF TECHNOLOGY CHOICE



Industries also vary by the scope of scale economies that are available to them. For some industries, the potential for large scale economies is quite high because of the nature of the production process and the nature of the market they serve. For the same reasons, the scope of economies of scale for some industries is limited. Where potential scale economies are high, and possibilities of achieving these through technology-based strategies exist, the desire to achieve large scale economies by means of technological change will be more important than where potentials for economies of scale are low.

Industries also differ in their respective demand or market conditions. In general some industries like food processing have a conservative market largely because of attitude of the general public in what they eat. In such industries, technological change tend to be very slow and can only proceed with extreme caution. In addition technology change tends to be incremental. For some industries too, the demand for their products may be price inelastic. Such industries tend to be production-oriented and the main interests in seeking technological developments may lie in reduction of costs and improved customer service. The products of such industries also may be highly standardised. The result is that it may even be very risky for a firm to introduce new quality since it may be alone in a market or may be trying to service a non-existent market (OECD, 1988). In contrast, the products of some industries may be market-oriented. Technological opportunities in such industries tend be based on in-house R&D which are kept as company secrets. In addition, firms tend to use technological developments to create niches in the market.

Finally, industries also tend to vary in their respective structures. Some industries may be dominated either by small firms, or large firms or both types of firms may be well represented. In all these cases a given technology will not be suitable to all the firms in the industry. For example, a high speed equipment developed to increase production output may not be suitable for the small-sized firms. In this case, the decision to adopt this technology may be delayed. Apart from differences in size of constituent firms, differences also exist in the number of firms in industries. Some industries are monopolistic while others are oligopolistic. These characteristics features also do have implications for competitive strategies. Generally, in monopoly situations the pressure to remain competitive is not there. In oligopoly, there may be a colluded effort which may create a fair amount of standard products on the market. In such situations, the need to resort to new technologies as a competitive weapon may not be strong.

The Technological Context

In the second instance, technology choice will vary among industries and even within industries according to the technological context, which refers to the R&D system and processes that generate and develop the the new technology and the characteristic differences between the new and the old technologies.

In some industries almost all the R&D activities that generate new technologies are located outside the industry. This may be due to the fact that the requirement of R&D activities may involve such a high amount of capital and highly specialised technical expertise beyond the primary activity of the industry. Or it may be due to the fact that the "lead time" and learning curve advantages of product innovations are so short that firms in the industry may think R&D activities for new ideas are not worth the cost and effort. In other industries, most R&D activities leading to new ideas may all be in-house, either because the production technologies may be such that the capital requirement and expertise are within the capability of the operating firms in the industry or because technological innovativeness is fundamental to firm survival. Still in some industries, there is the need for co-operative R&D activities. In such industries, information sharing and colloborative efforts are important in the day to day operations of the firm.

Where most of the new developments are externally generated it will be expected that the new technology will be marketed to the industry as a whole. As LeHeron (1973) has pointed out, an exception may occur if some arrangement concerning the technology's development has been contracted between the producer of the technology and some user firms. In effect, other firms can have the opportunity to consider the adoption of the new technologies much earlier since information about the technology will be more public than private from the point of view of the users. This may speed up the diffusion process. On the contrary, where most of the technologies are developed by firms within the industry, for reasons of appropriability, secrecy will be the strategy to protect the innovation. In this case, the "lead times" and learning curve advantages will be longer since information about the innovation will not easily disseminate to foster technology choice consideration by other firms.

Almost invariably, decisions made by firms regarding the type of technologies to use involves a comparison of characteristics and attributes of a set of technology options. Most of the characteristic attributes have been established by previous studies. Among these are the degree of uncertainty involved (Mansfield, 1963). Generally, it is expected that the less the uncertainty involved, the more confident firms will be in making decisions regarding rejection or adoption of the technology. In most cases the level of uncertainty may be determined partly by the stage of the technology in the innovation cycle, the experience of other companies, and partly by the reversibility of the choice decision. Generally, the uncertainty surrounding technologies which have reached their "mature" stage will be much less than one which is in its initial stage. There is also the question as to whether or not decision are "reversible" which in turn, depends in part on the nature of the technology. It will be much difficult to reverse decisions made about technologies involving heavy capital items once the items have been installed than it will be for decisions involving small capital items. The extent to which the new technology is compatible with or a complement to other technologies in use is also important. Often times since technologies tend to have strong industrial focus, an introduction of one technology may require a chain of other technological adjustments and overhaul throughout the entire production line or even the entire plant/firm. In this case technology choice decision may either be delayed or even avoided because of the complexity of the situation, or lack of supporting technologies or lack of funds to establish the necessary supporting infrastructure.

The R&D processes that are responsible for the advent of the technology also determine the range of choice of technology that will be available to firms. This is because technology itself is developed. The reason why it was developed and how it was developed is therefore important to understanding technology choice. Once innovated, technology is constantly refined or modified through experience and further R&D activities. In particular, where the technology is developed by firms outside, competition among these "technology" firms for markets can initiate a chain of technological activities which can shift technological trajectories within given technological paradigms. Thus improved versions and variations of the original technology may emerge and new applications will be experimented, some of which will be successful. Such developments will reduce the risk and uncertainty that surrounded the innovation at the early stage and thereby increase the confidence of users. Such decisions tend to widen the range of choice for users and may provide opportunities for firms to make various decisions within the context of their own needs. Also, they can bring in other users which were initially outside the so-called potential users. Thus firms which formerly could not use the technology because it was incompatible to their situation may be able to use it at a later (McArthur, 1987). For these reasons, the R&D proceses and organisation by which the technology in question emerged constitute an important part of the technological enviroment within which firms make their technology choices (Brown, 1975).

Another important distinction is between "core" and "auxiliary" technologies (OECD, 1988). A manufacturing firm stands or falls with its core technology. Core technologies are naturally genuine to manufacturing firms while auxiliary technologies are not. Thus machines for spinning and weaving, for example, will be core technologies for the textile industry, while conveyor belts for moving things between work stations, and other machines for packaging and storage are examples of auxiliary technologies. Clearly, the behaviour of firms regarding the need to make decisions about core technologies will not be the same as when they have to make decisions about auxilary technologies.

The relevant questions within the technological context that need to be examined in order to understand technology choice then are: What is the nature of the new technology relative to the existing one? Why was it developed? Who developed it? How did it develop? What strategies were pursued by suppliers to develop and market it?

The Spatial Context

In the third instance, technology choice will vary according to the spatial context, which is the locational environment and scale at which the technology choice is made. Thus technologies relate to local and international differences in resources characteristics, environmental conditions, government regulations, trade policies and even ideological beliefs. A given technology may be suitable globally but not nationally or locally because of differences in resource inputs, national industrial structures and specialisations, national regulations and trade policies. These may serve as constraints to technology choice decision. Differences in R&D incentives also have considerable influence on the generation and adoption of new technologies. Sometimes national policies or preferences may advocate for or prevent the use of technologies of a different national origin. In this case the technology choice decisions may not favour adoption until a national capability in the technology may be gained.

In some cases these spatial differences tend to require changes in the technology in question. In some cases these changes may be minor while in others they may be quite radical, resulting in a complete shift in trajectory. The development of such variations usually takes some considerable R&D effort during which an innovation may not be adopted in certain firms in the industry because it is not suited to their regional locations. This may account for delay in adoption of the innovation in that region. Even within the same country and region, manufacturing firms within the same industry may relate to a given technology in different ways as a result of differences in locational characteristics. As a result of resource endowments and historical factors , manufacturing industries, in most cases, tend to be over-represented in certain regions and under-represented in others. For the same reasons, different regional industrial structures come to exist. Certain regions may have more ageing plants than others while others may have more multi-plant or large firms than the others. In this case, certain regions may be favourably placed to shoot ahead while others may not. Thus the influence of industrial structure on technology choice, dicussed under the industrial context, may manifest itself in differences in regional technology choice pattern. Finally, locational differences may affect the firm's access to information. In general firms located in a metropolis are able to receive and access information about new ideas earlier than firms in non-metropolitan locations.

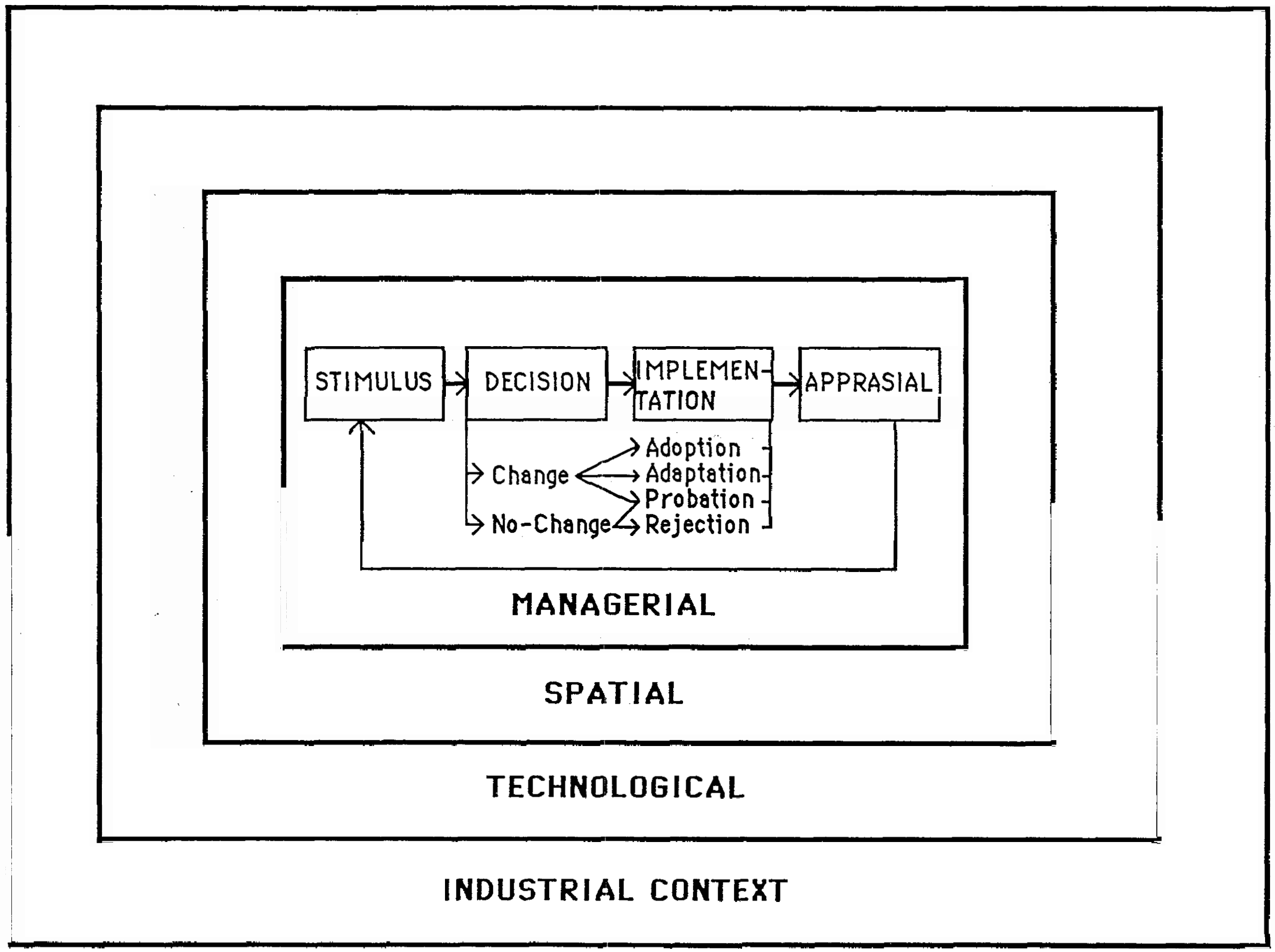
In addition to these, the spatial context to technology choice can be seen in the fact that manufacturing firms operate and make decisions which relate to different spatial scales. For example, export markets may be *global*; trade policies (eg tariffs) may be *continental*, as in the case of the European Economic Community (EEC); taxation laws and other business incentives may be *national*, that is pertaining only to country of the firm's location; labour markets and other resource inputs may be *local*, that is pertaining only to the sub-national area or city in which the firm is located. Where input resources and markets are global manufacturing firms do not only compete with firms in their own country of location but with firms in other countries. Even where input resources and markets are domestic, except that there is a very high degree of national protection, manufacturing firms will have to compete on the product market with firms located outside the national boundary. In this case such factors as input characteristics, production and distribution cost differentials and product differentiation will determine who gains the competitive edge. Where the role of production technologies is dominant, it will mean that technology choices by firms within the country will be highly influenced by the choices being made by their global, international, national and local competitors. For this reason too, locational proximity to competitors may have significant influence on technology choice (Hagerstrand 1953).

The Managerial Context

Finally, as an investment decision, technology choice will vary according to the managerial context, by which is meant the corporate organisational structure, strategy, objectives and philosophy, innovation and investment history and capabilities, within which the decision-making process that leads to the choice of technology is made. Generally, it is expected that decision-making process of firms in this regard consists of three broad interrelated stages: *stimulus, decision* and *implementation.* The *stimulus* stage is the stage where specific events will initiate the technology choice process. These events may generate from internal or external sources or both. Whichever source, the stimulus stage will naturally progress into the the second stage which is the *decision* stage, where the firm makes preliminary decisions regarding the innovation as to whether it wants it or not (Fig 2.5). If the firm decides for a change, it can do so by *adoption* which, in the strictest sense, means acceptance without any modification at all or by *adaptation*, which is accepting the technology with modification ; or it can choose to wait and see how the technology performs with other firms/plants till it has got enough information to decide again *(probation).* If the decision is not to change, the implication might be *probation* or *rejection*, in which the plant will stick to its current technology.

At the *implementation* stage, the decisions are put into practice. If the decision is for adoption or adaptation, the decision will be further pursued with greater details before final action and will include a detailed *search* process (Gold et al, 1984; Thomas, 1985) a detailed *evaluation* process and *purchase and installation* of the technology. The detailed search will involve a search for more information about the technology and detailed capital cost estimation the technological capabilities of the various choices, the capital investment involved as well as experience of previous users. The evaluation process of the various technological options (Gold, et al 1984) will involve the examination of the alternative technologies against its current technology on one hand and among the various options within the new technology, if any, on the other hand. However, the ease with which these processes can be executed, the duration, the timing and the speed all depend upon such managerial components as corporate innovativeness, strategy, structure, R&D activities, past investment history, past innovative history, productive objectives and other components in the industrial, technological and spatial contexts.

FIG. 2.5: THE TECHNOLOGY CHOICE PROCESS



As an investment decision, technology choice is a long term commitment and a key element of *managerial or organisational strategy.* A determining factor of this managerial strategy is the innovativeness of the firm and firm executives. The dimensions of this innovativeness may range from *offensive, defensive, imitative, dependent, traditional* (Freeman, 1974, 1982); or *innovators, early adopters, early majority, late majority, and laggards* (Ryan and Gross, 1943; Rogers and Shoemaker, 1971). Firms pursuing offensive strategy are mostly considered to be innovators, defensive the early adopters of the innovation, imitative the early majority, dependent the late majority and traditional, the laggards.

Beyond these general strategies, however, there are other important elements of the managerial context relevant to understanding technology choice. The first is the past innovative history (Thomas, 1985). Firms that have demonstrated strong innovativeness in the past want to maintain their reputation and therefore will be more likely to move into new areas of technology. A firm's past investment history plays an important part in making similar investment decisions such as technlogy choice. On one hand, mistakes made in previous investment decisions can make a firm swing from one innovative strategy to another. On the other hand, successful investment decisions in the past can make a firm more aggressive in making further investment decisions. Past investment history of the firm can also determine the timing of making decisions about new technologies. A firm which has just gone through a major investment, such as plant-wide modernisation, will most likely be unable to invest in an expensive new technology which emerges soon after the modernisation, unless it is absolutely necessary for the firm's existence. Corporate production objectives may also influence its technology choices. For example, in industries which have a wider range of products technological options will also be wide. As firms tend to specialise in the manufacture of particular products, certain technologies in the industry become more important to them than others which may reflect in differences in attitude towards new technologies in the industry.

Organisational structure may also affect the complexity of decisions and may prolong the duration of the entire process. In multi-plant firms, for example, the decision to adopt the technology may require location decisions. Such decisions may also have to be based on detailed search which may make the decision-making process longer. Other features like ownership, and whether or not the decision-making process is centralised can add to delay of final decisions. In all probability, it can be expected that technology choice in decentralised corporate structure will proceed at a faster rate than in a centralised system. The manner in which evaluation is done can affect technology choice. The use of consultants in the evaluation stage for example can increase search costs. To circumvent this problem, firms may deliberately shorten the search process and limit the range of choice. Where the technology is developed by a supplier, managerial preferences for suppliers will have an important influence on the choice of technology. The focus of the managerial context of technology choice then is the decision-making process leading to the adoption of the technology and is the crux of the technology choice approach to the study of the diffusion process.

Conclusion

Technology diffusion within the manufacturing sector is the direct outcome of investment decision-making by manufacturing firms. However, these firms do not exist in vacuum. Instead they exist within broader environments which tend to shape their actions even as they seek to influence the environments. In particular, they exist within certain industrial milleau with specific resource and production function characteristics. The general forces that affect technological changes in the industry affect the individual firms in varying degrees. Besides, manufacturing firms make decisions within specific geographic contexts. The evolution and the development of the technology is another influence on the decisions made by firms. Finally, manufacturing firms differ by how they make such important decisions as technology choice. While they may all have similar procedures, differences in corporate strategy, corporate structure, investment history, evaluation procedure and innovativeness play important roles in how, why and when technology choices are made. For these reasons, a study of technology diffusion within the manufacturing sector needs to be studied by explicit incorporation of technology choice and within the wider contexts of industrial, technological, spatial and managerial environments of the time. In the following chapters an attempt will be made to examine the the diffusion of the twin-wire paper machine in Canada within the four main contexts of technology choice.

CHAPTER III

THE INDUSTRIAL CONTEXT

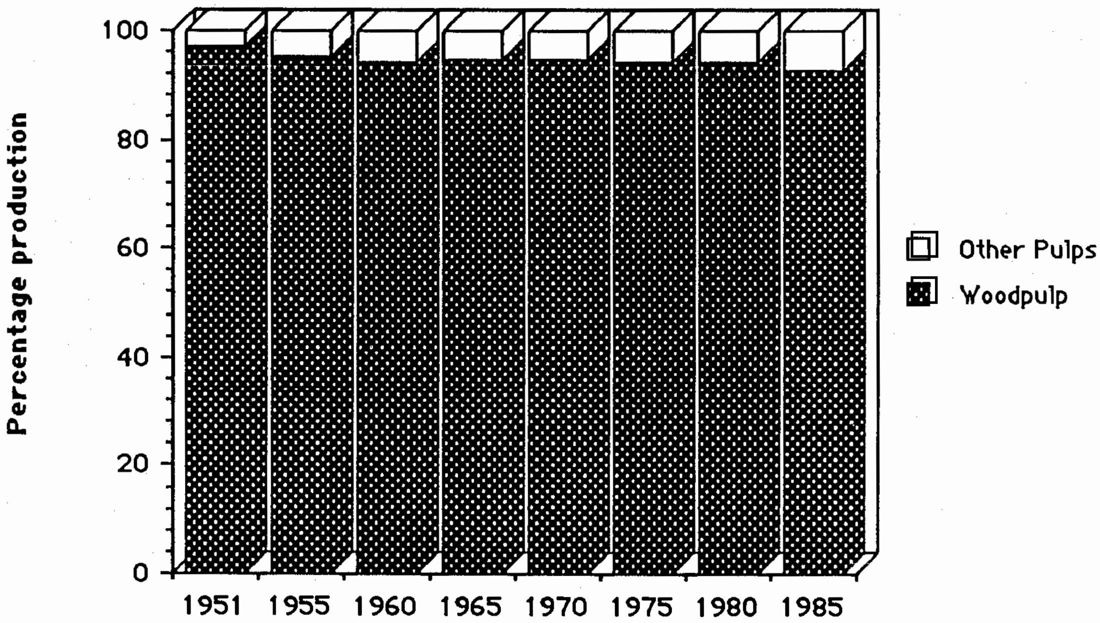
Technology choice stems from the demand for technology by manufacturing firms. The basic impetus for this demand derives from the competitive situation of the firm which in turn depends on the dynamic forces that affect the nature of the industry within which the firm is operating. Industries vary in their structure, demand and supply conditions as well as forces that affect them. Even within the same industry, different production sectors may respond differently to these general forces because of differences in their product, input, technology and market characteristics. For these reasons, to understand the choice of a given technology in any manufacturing sector, it is important to understand the basic conditions and characteristics of the industry and the factors that are important in shaping these characteristics and how these affect technology choice in the industry. The purpose of this chapter therefore is to put the study into its specific industrial perspective. It examines the main features and trends in the pulp and paper industry that are considered relevant to understanding technology choice in the industry from 1950 to 1988. First, readers are introduced to some basic information regarding the definition, products, leading regions and importance of the pulp and paper industry. Second, the main characteristics of the industry structure are outlined. Third, the characteristic features and trends in the demand, supply and trade in the industry and the factors affecting them are examined. Finally, the implications for technology choice in the industry are outlined.

The Pulp And Paper Industry

The pulp and paper industry is that sector of manufacturing activities that uses organic residuals as basic raw materials to produce a fibrous raw material, called *pulp*, which is later used to produce *paper*. The two products, pulp and paper, are broadly defined commodities that can be further subdivided. By source of raw material pulp can be classified into two broad subdivisions namely *wood pulp* and *other fibre* of which wood pulp is the most important. As indicated by Fig. 3.1 it accounted for 97 per cent of the total 38.8 million metric tons produced in the world in 1951, and according to FAO statistics it was the only commodity in the world's pulp trade until about 1970. In 1985 it accounted for 92.8 per cent of the 140.7 million metric tons produced. By production technology wood pulp is classified into two broad classes namely, *chemical pulp* and *mechanical pulp*. In 1951, chemical pulp accounted for 65 per cent of the total 37.3 million wood pulp production and consumption. By 1985, this had increased to 76.9 per cent (Fig. 3.2). In terms of both imports and exports, chemical pulp accounted for 76 per cent of wood pulp trade, with mechanical pulp taking the remaining 24 per cent (Fig. 3.3). By 1985, the proportion had reached 93.5 per cent in both imports and exports trade (Fig. 3.3).

In the paper sector, there are three broad classes of products namely newsprint, printing and writing paper and other paper and paperboard. Newsprint refers to uncoated paper containing at least 60 per cent mechanical wood pulp and generally weighing between 40 g/m^2 and 60 g/m^2 (FAO, 1986). Printing/writing paper refers to paper other than newsprint which is suitable for printing and business purposes, writing, sketching and drawing. Other paper refers to tissue, wrapping and packaging paper and paperboard. In turn, tissue comprises all household and sanitary paper such as absorbent paper, towels, napkins, facial tissue, toilet paper, and wadding disposables. Wrapping and packaging paper can be further divided into linerboard, corrugating medium and kraft papers, while paperboard refers to all paper having a thickness of more than 0.3 mm (Smook, 1982) and which are used in the manufacture of cartons and other food cases. Newsprint and printing and writing paper are sometimes referred to as cultural papers while the remaining grades, apart from tissue, are referred to as industrial papers. Figure 3.4 gives proportions that have been taken by each of these broad classes in the total production of paper since 1951 from which it can be seen that over the past three decades, other paper and paperboard has continued to be the largest product group of the industry, with printing and writing paper becoming more important than newsprint. In contrast, the exports structure over the same period shows a

FIG. 3.1: PULPING SECTOR PRODUCTION STRUCTURE, 1951-1985



Source: FAO Yearbook of Forest Products

FIG. 3.2: WOOD PULP PRODUCTION STRUCTURE, 1951-1985

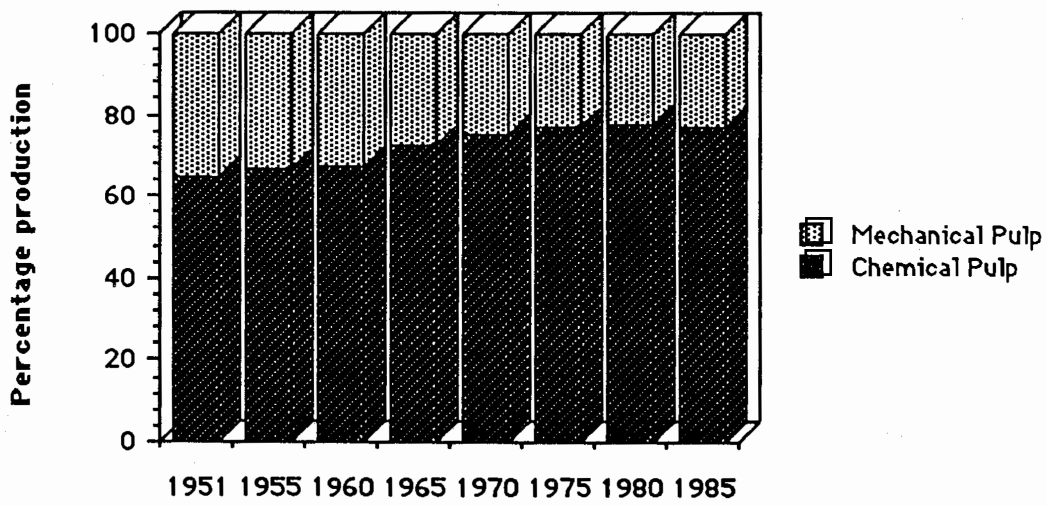
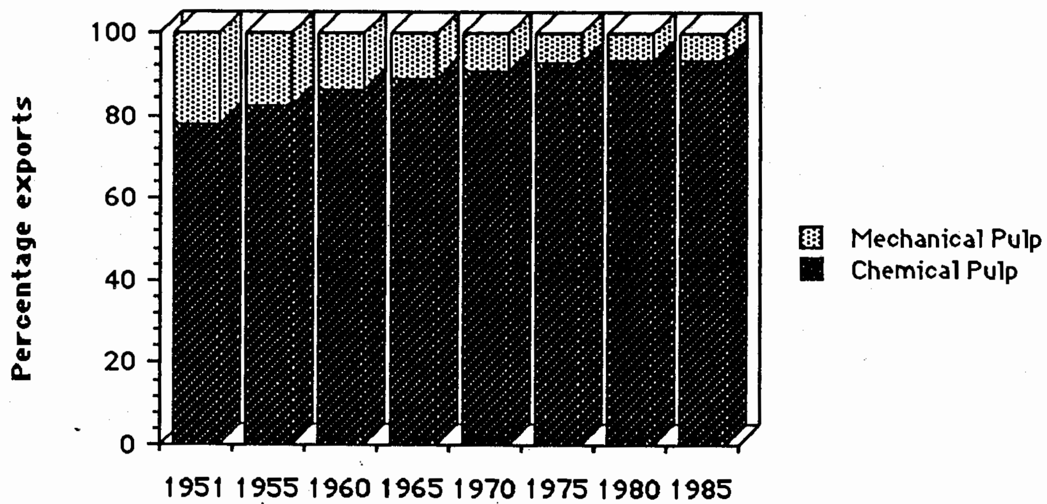


FIG. 3.3: WOOD PULP EXPORTS STRUCTURE, 1951-1985



Source: FAO Yearbook of Forest Products.

FIG. 3.4: PRODUCTION STRUCTURE OF PAPER, 1951-1985

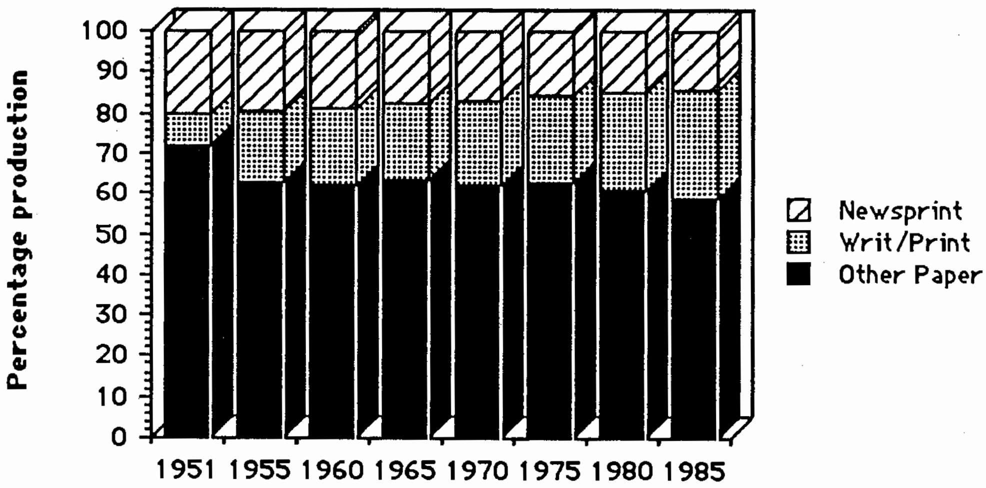
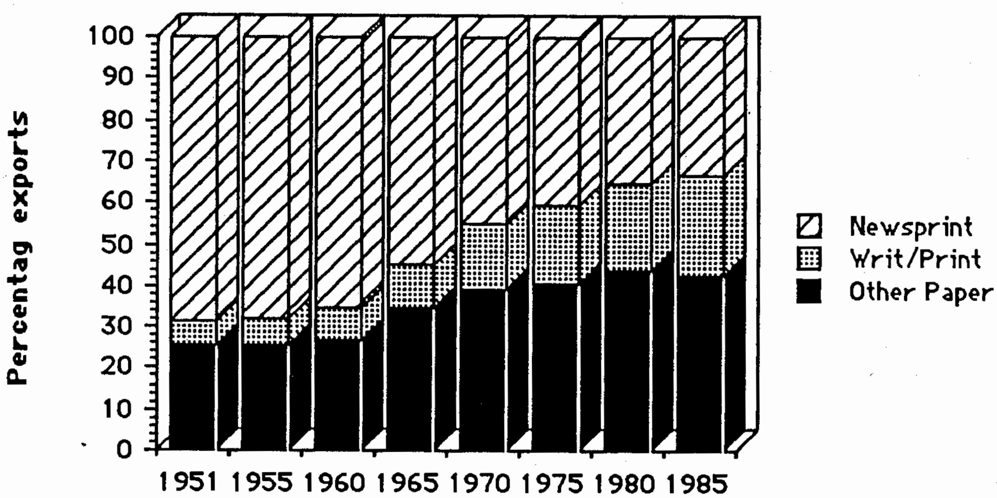


FIG. 3.5: EXPORTS STRUCTURE OF PAPER, 1951-1985



Source: FAO Yearbook of Forest Products.

different picture (Fig. 3.5). Newsprint, which used to be the largest export commodity of the sector has been on the decline, particularly since 1970, while other paper and paper board as well as writing/printing paper has been on the increase.

Spatially, the pulp and paper industry is truly global and is located on all the continents of the globe. However, by virtue of its source of raw material, which until recently was dominated by coniferous softwoods, large requirements of energy, highly skilled labour, modern technology, market and capital needs and by virtue of historical factors, the modern pulp and paper industry, like most manufacturing industries, has come to be concentrated largely in the Developed Market Economies (DMEs). Even the most advanced regions of the Centrally Planned Economies (CPEs), as well as the Developing Market Economies (DPEs), play a lesser role. Thus in 1951, the DMEs accounted 94.4 per cent of total pulp production, while CPEs and DPEs accounted for 4.7 per cent and 4.8 per cent respectively. By 1985, even though the DMEs position had declined, they still accounted for 77.4 per cent of the total production (Fig 3.6). In consumption DMEs accounted for 93.2 per cent in 1951 and 76.5 per cent in 1985. In both imports and exports trade, the DMEs accounted for 97.4 per cent in 1951 and 83 per cent in 1985 (Fig. 3.7). In the paper sector, the dominance of the DMEs is again evident in production (Fig. 3.8), consumption (Fig. 3.9), exports (Fig. 3.10) and imports (Fig. 3.11).

Within the broad category of the DMEs, the industry is concentrated in three main subregions: North America, Europe and Asia. The North American sub-region comprises the United States (US) and Canada; Europe divides into two groups; first is the European Economic Community (EEC), dominated in production by the Federal Republic of Germany (FRG), then France and Italy, and second, the Scandinavian countries of Sweden, Finland and Norway. The Asian region is dominated by Japan. Within the CPEs the most important are the USSR and then China while within the DPEs are Brazil, Mexico, and Chile and India. The top ten countries in each of the major product group of the industry for selected years from 1951 to 1985 are illustrated by Fig. 3.12 and the per capita consumption of paper for some selected years since 1965 are given by

FIG. 3.6: PULP PRODUCTION BY REGION, 1951-1985

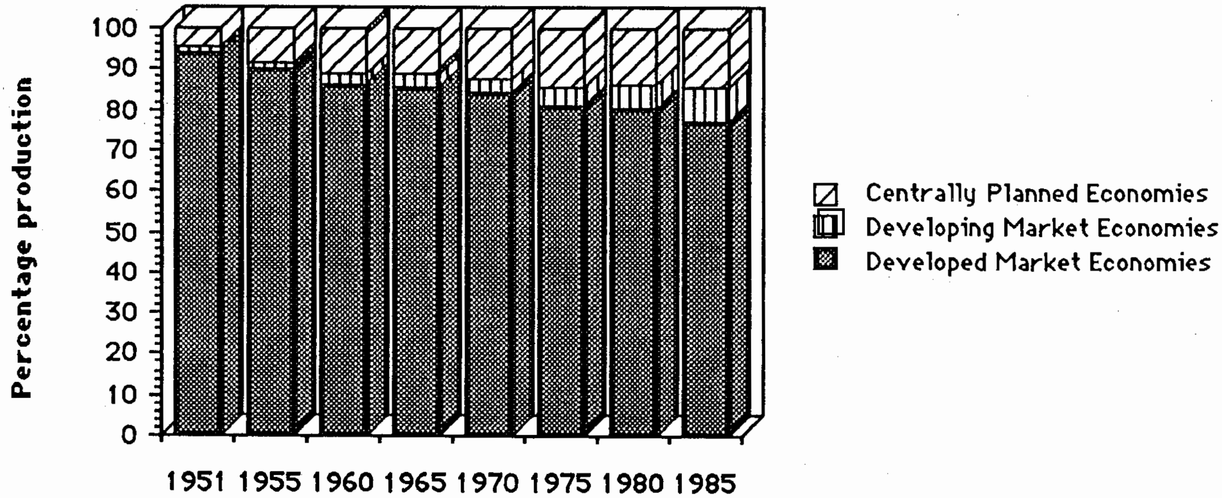
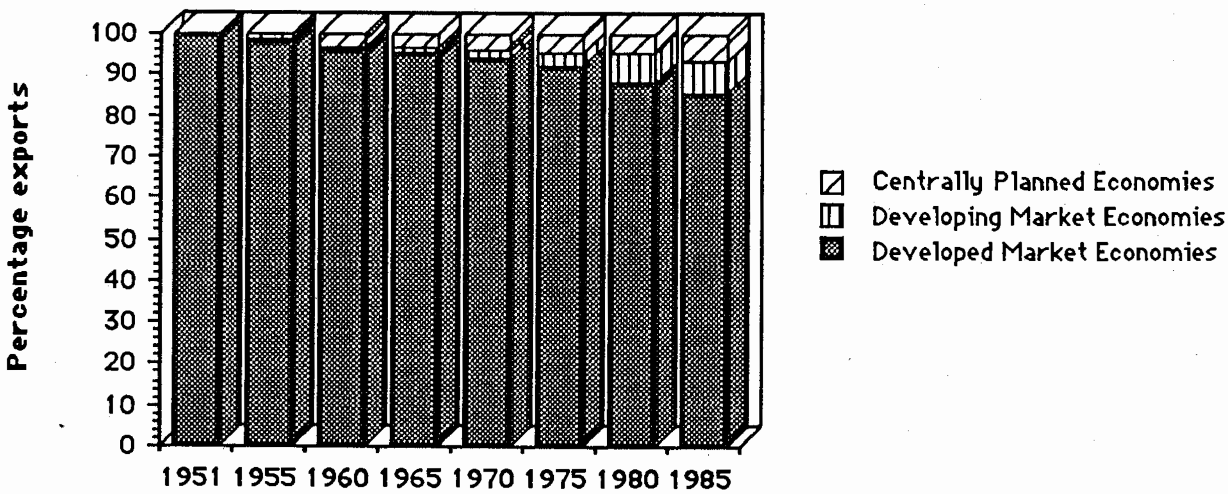


FIG. 3.7: PULP EXPORTS BY REGION, 1951-1985



Source: FAO Yearbook of Forest Products.

FIG. 3.8: PAPER PRODUCTION BY REGION, 1951-1985

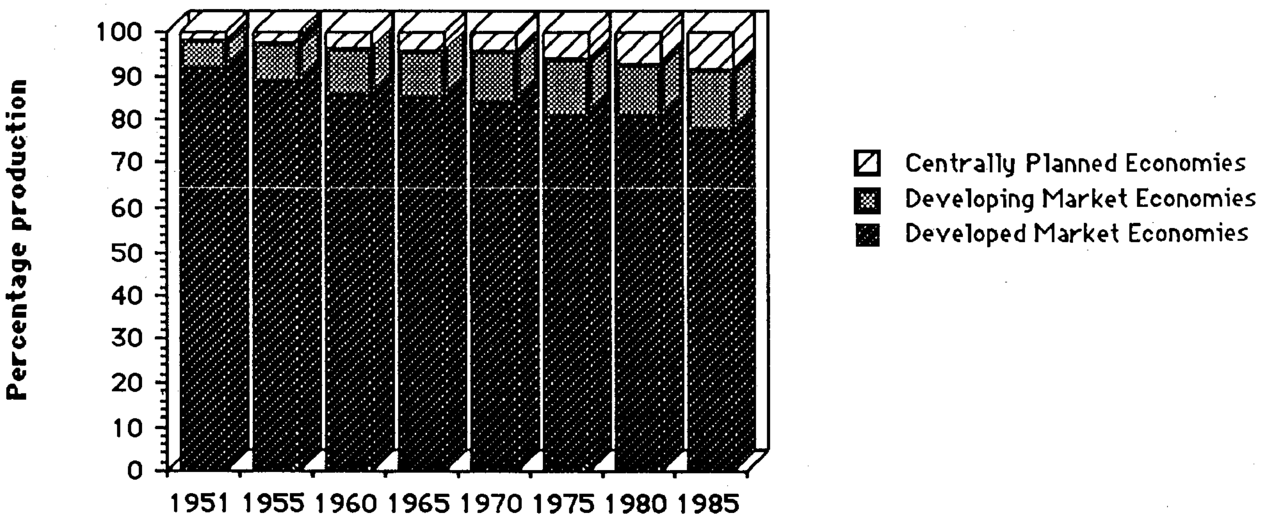
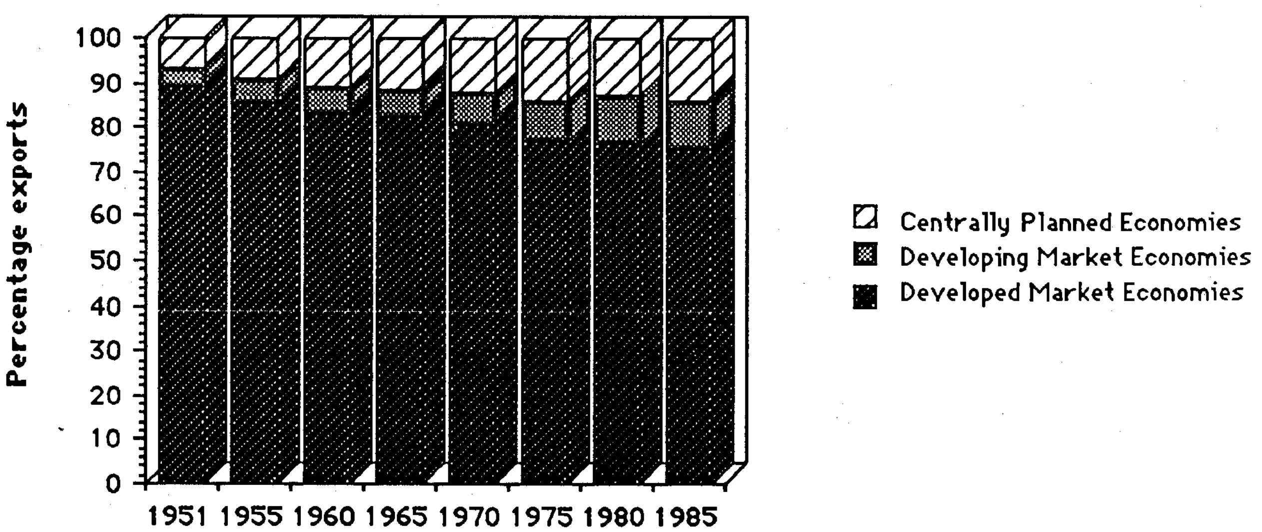


FIG. 3.9: PAPER CONSUMPTION BY REGION, 1951-1985



Source: FAO Yearbook of Forest Products.

FIG. 3.10: PAPER EXPORTS BY REGION, 1951-1985

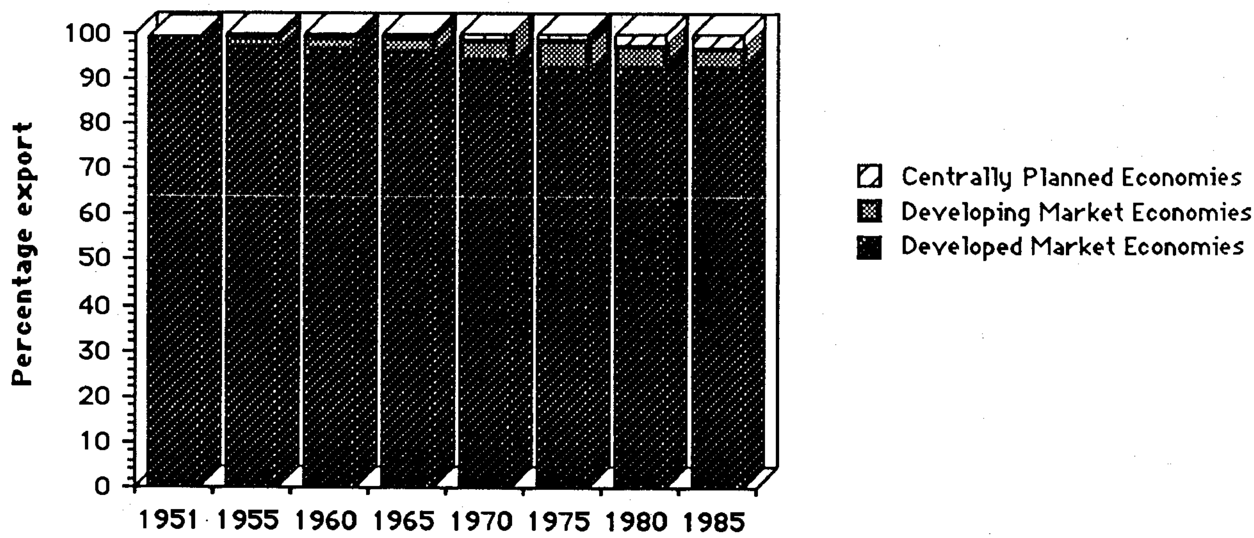
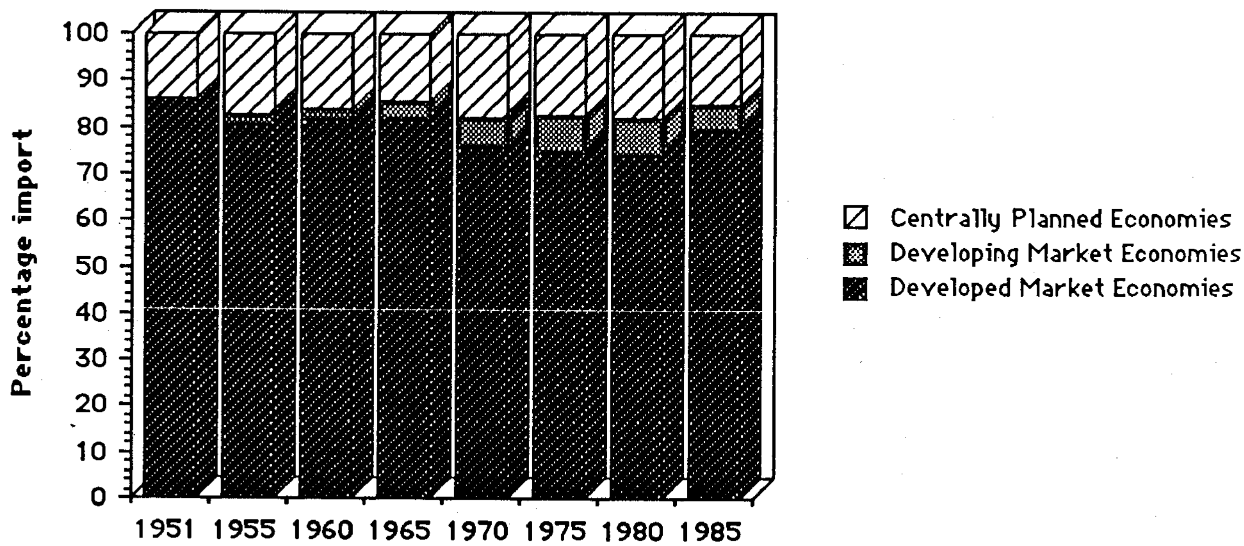


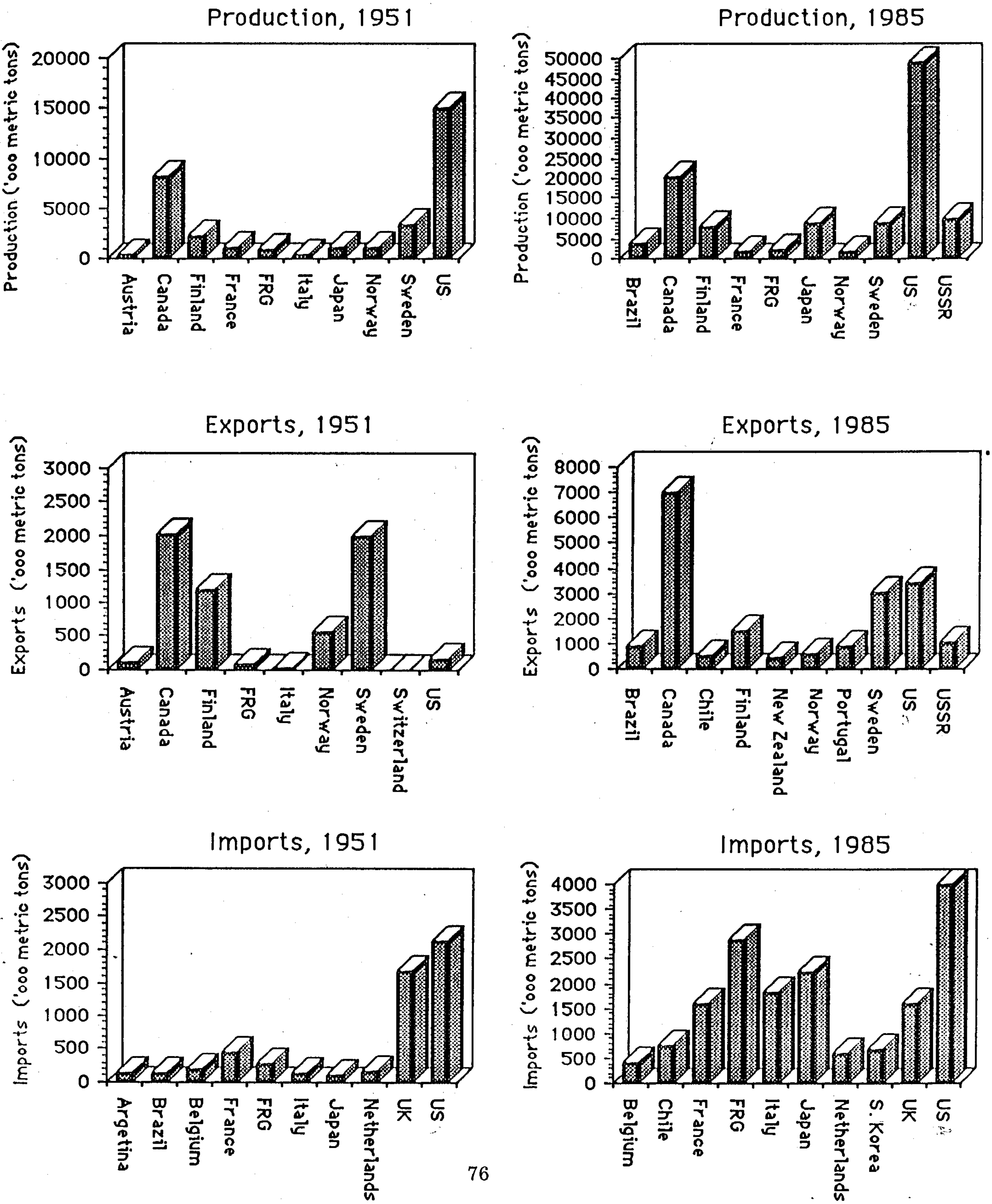
FIG. 3.11 PAPER IMPORTS BY REGION, 1951-1985



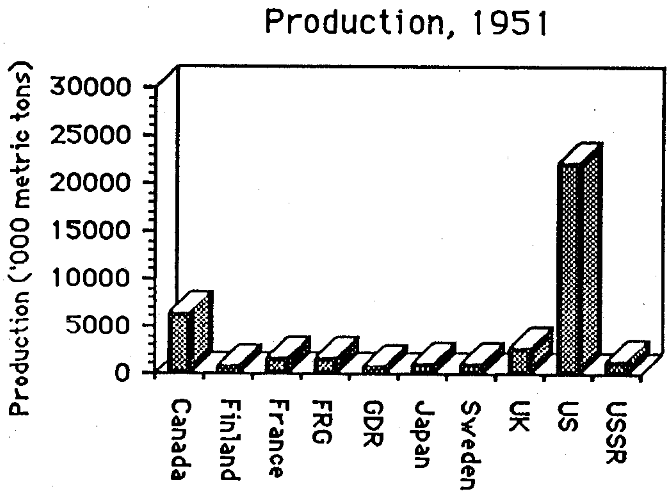
Source: FAO Yearbook of Forest Products.

FIG. 3.12: TOP TEN COUNTRIES IN THE PULP AND PAPER INDUSTRY IN SELECTED YEARS

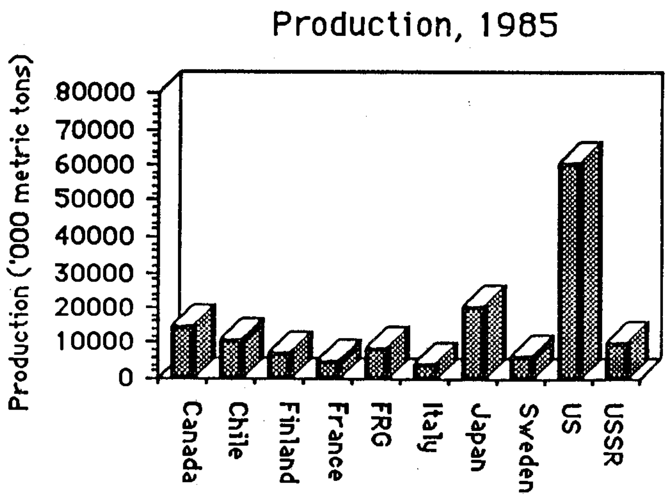
Wood Pulp



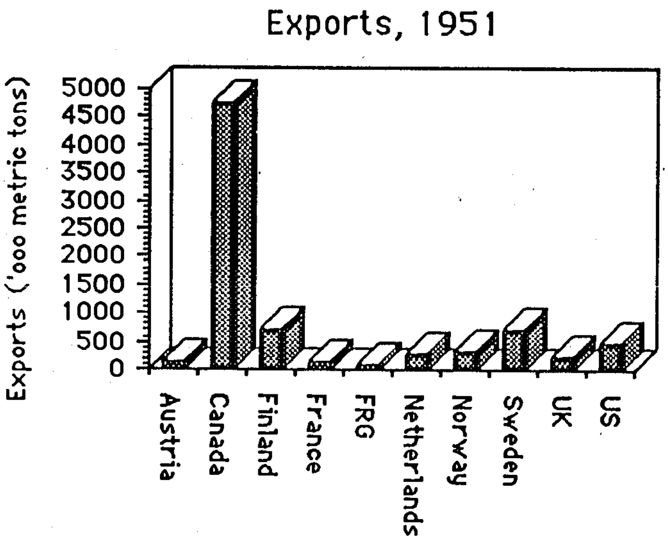
Paper



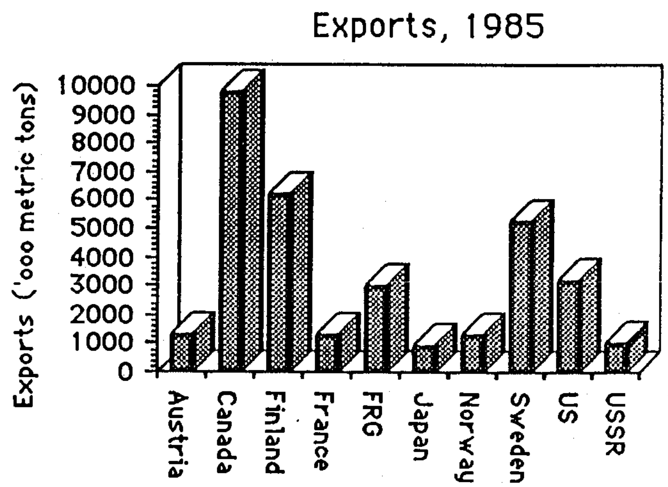
Production, 1951
Production ('000 metric tons)
30000
25000
20000
15000
10000
5000
0
Canada
Finland
France
FRG
GDR
Japan
Sweden
UK
US
USSR



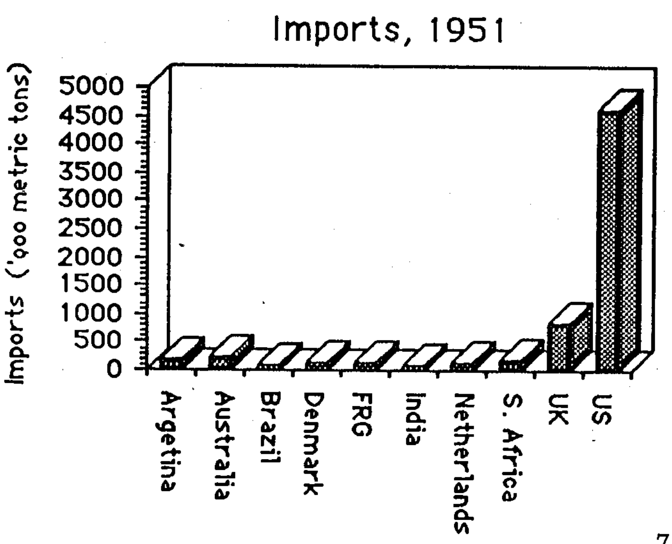
Production, 1985
Production ('000 metric tons)
80000
70000
60000
50000
40000
30000
20000
10000
0
Canada
Chile
Finland
France
FRG
Italy
Japan
Sweden
US
USSR



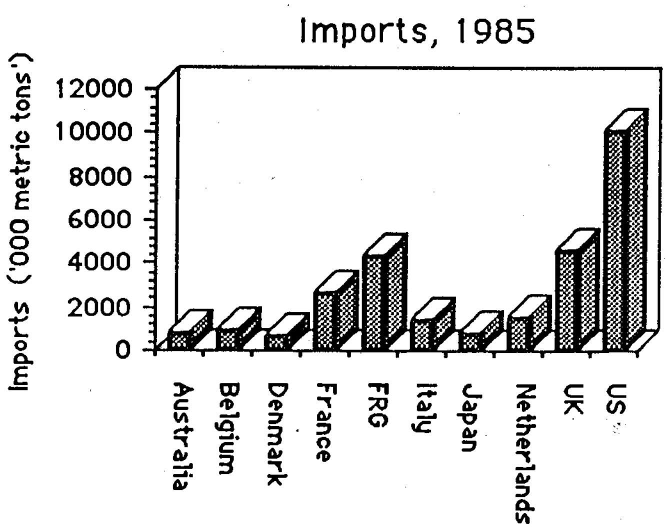
Exports, 1951
Exports ('ooo metric tons)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Austria
Canada
Finland
France
FRG
Netherlands
Norway
Sweden
UK
US



Exports, 1985
Exports ('ooo metric tons)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Austria
Canada
Finland
France
FRG
Japan
Norway
Sweden
US
USSR



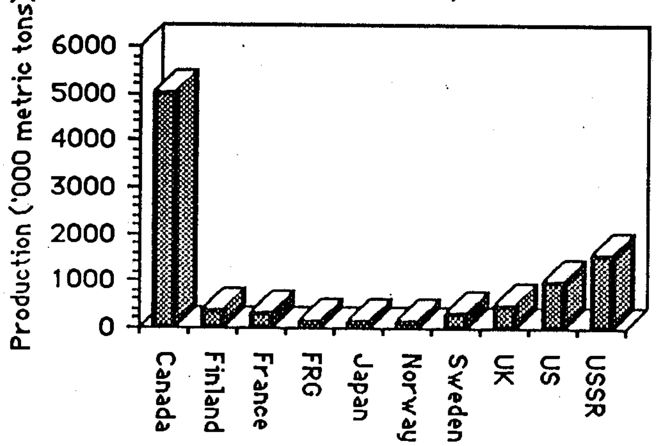
Imports, 1951
Imports ('ooo metric tons)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Argetina
Australia
Brazil
Denmark
FRG
India
Netherlands
S. Africa
UK
US



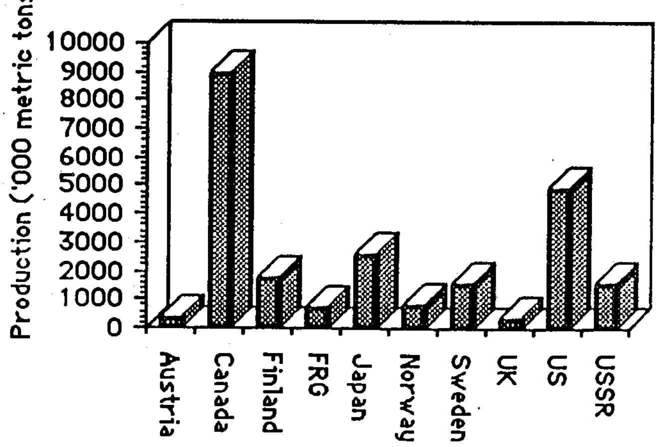
Imports, 1985
Imports ('000 metric tons')
12000
10000
8000
6000
4000
2000
0
Australia
Belgium
Denmark
France
FRG
Italy
Japan
Netherlands
UK
US

Newsprint

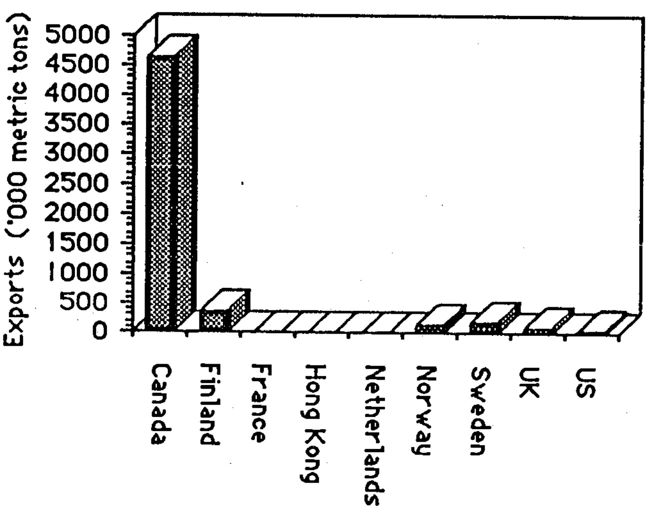
Production, 1951



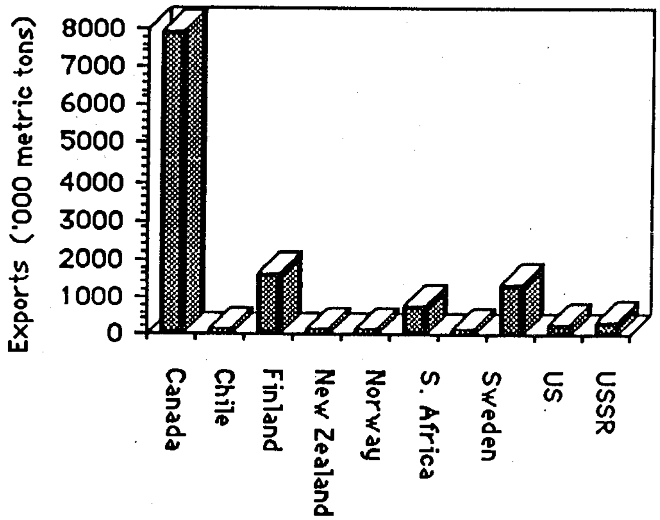
Production, 1985



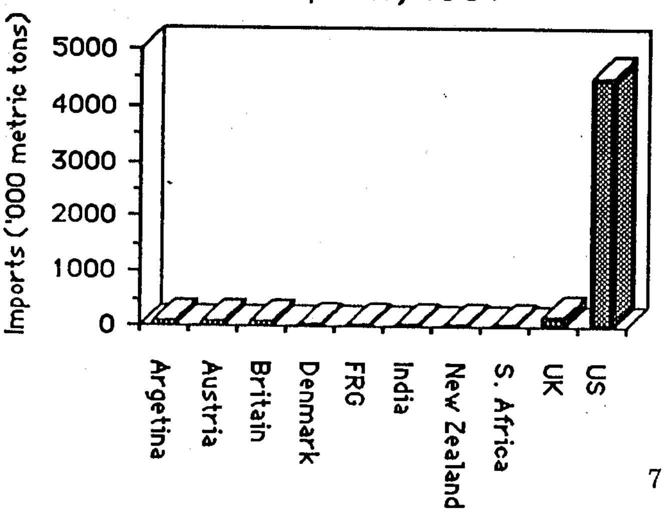
Exports, 1951



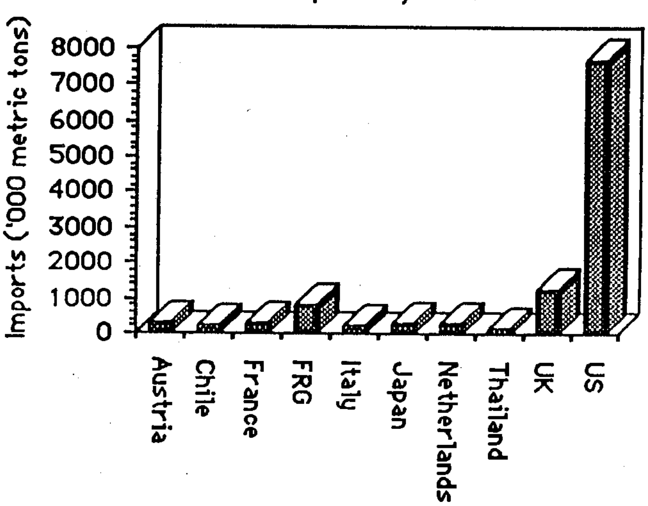
Exports, 1985



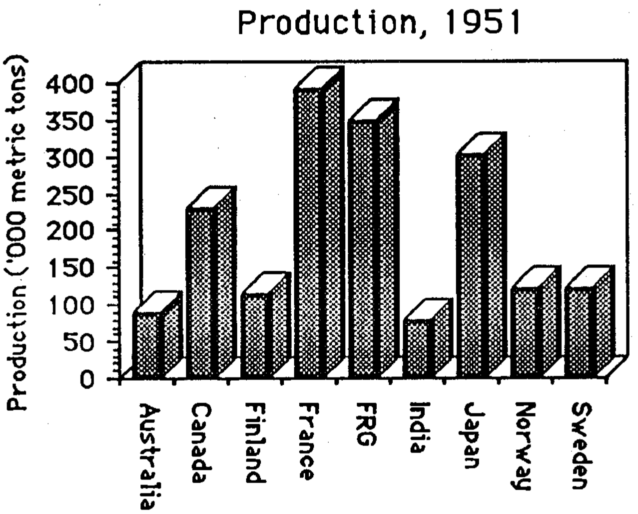
Imports, 1951

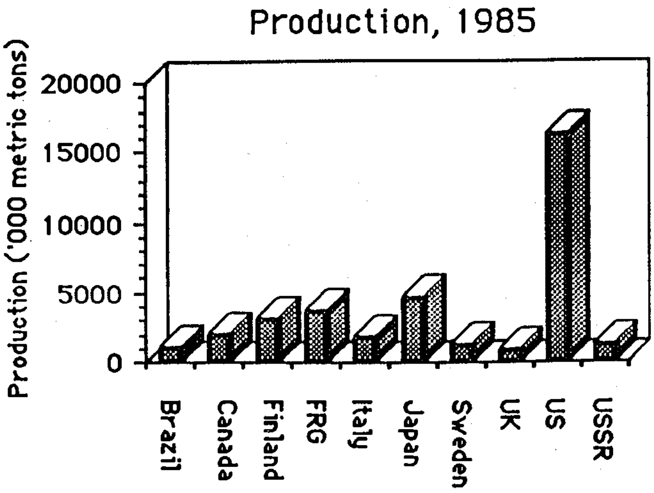


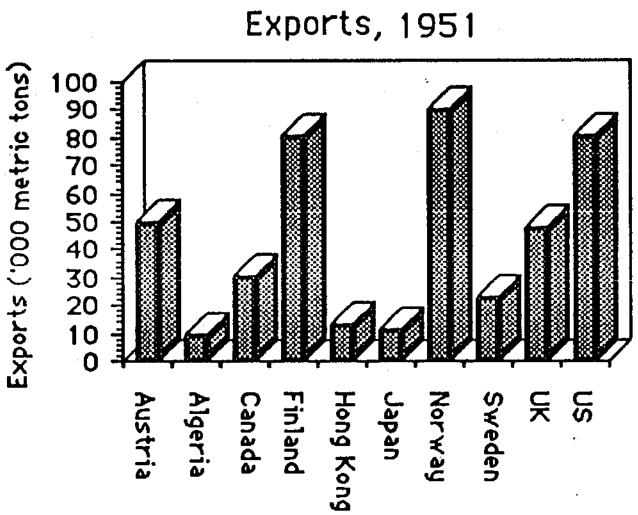
Imports, 1985

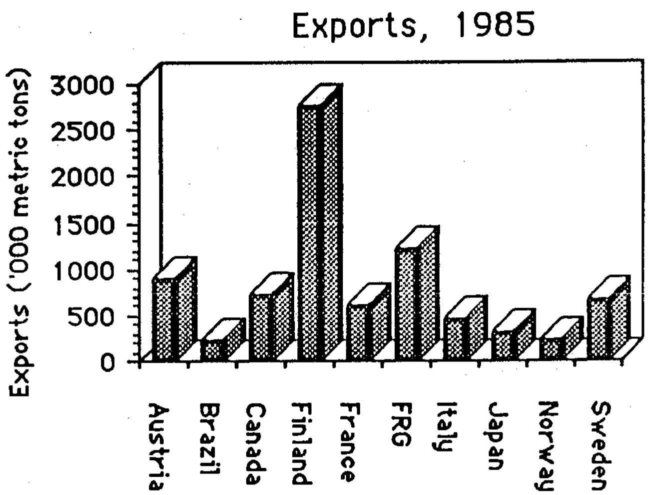


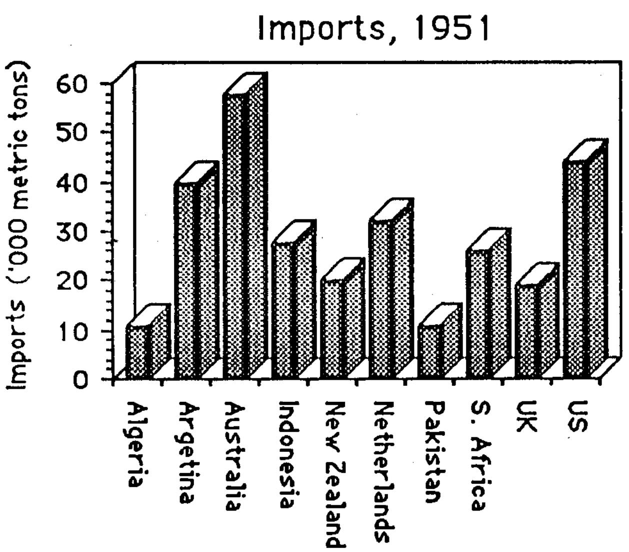
Printing + Writing Paper

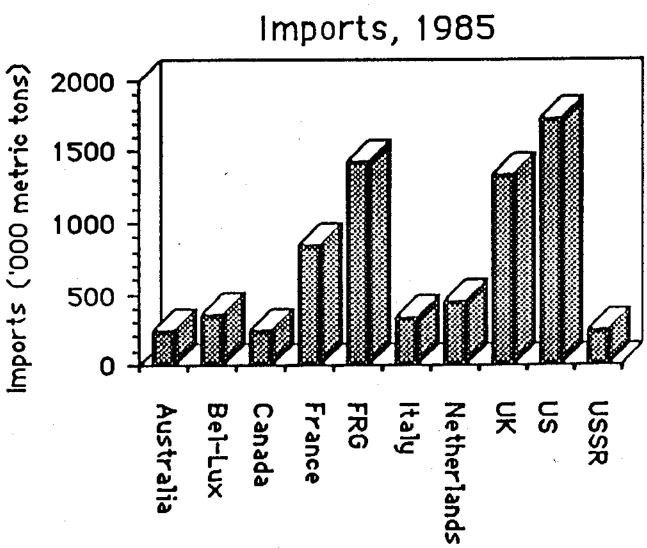




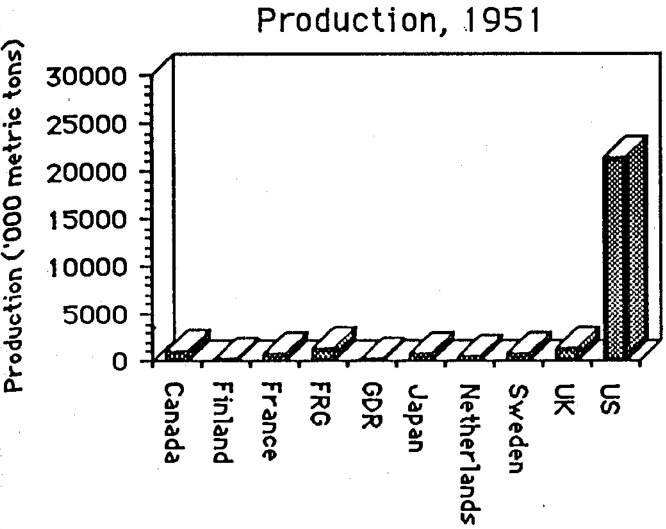


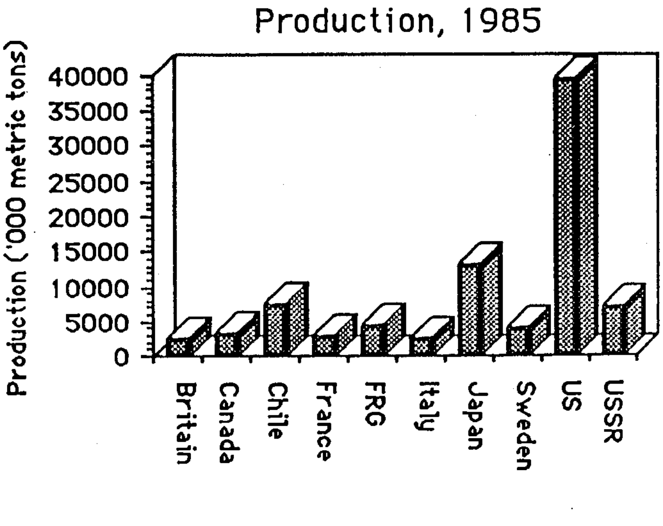


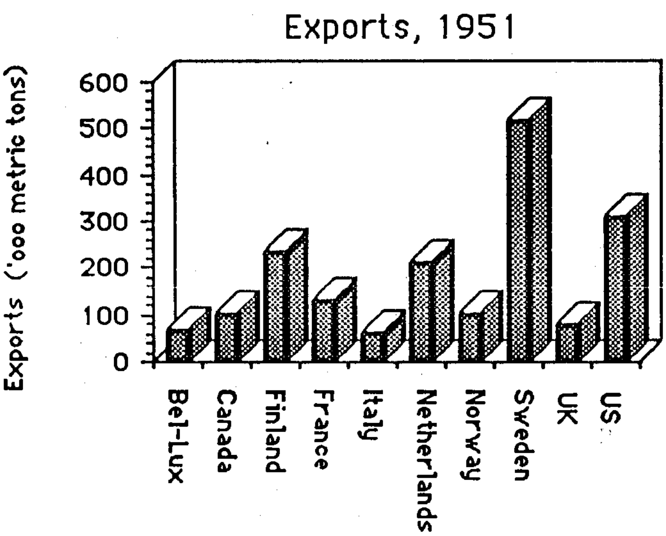


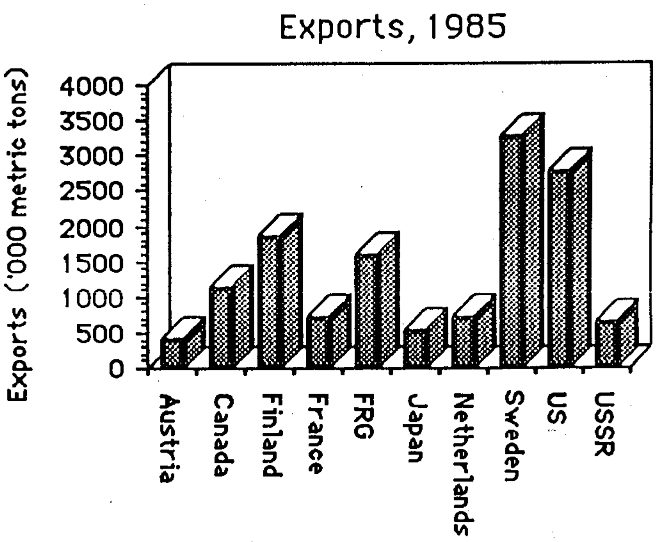


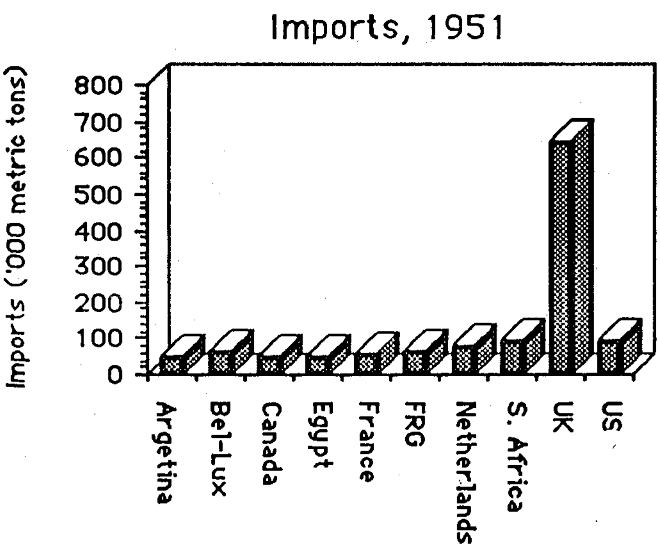
Other Paper + Paperboard











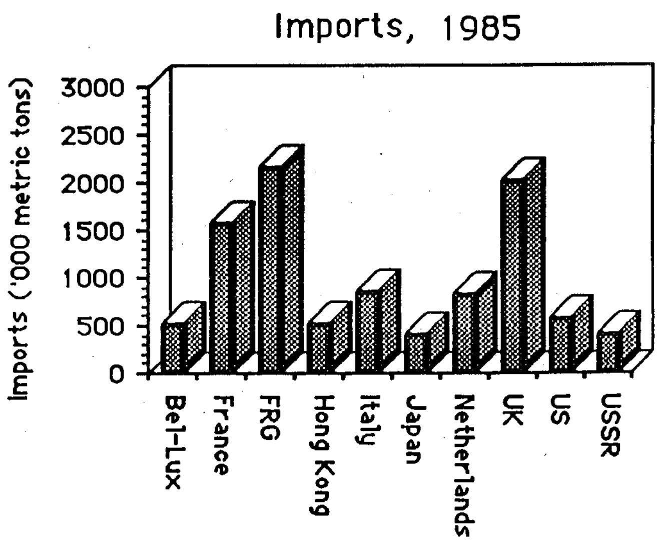


Table 3.1 **Per Capita Consumption of Paper And Paperboard In Selected Countries and Years**

Country	1965	1975	1985
US	214	252	286
Sweden	160	202	222
Canada	138	173	209
Finland	117	170	189
Denmark	109	155	181
Switzerland	115	155	178
FRG	102	132	174
Japan	72	132	169
Belgium	83	127	156

Source: OECD, 1988 p. 208.

Table 3.1. Clearly, the United States is the dominant producer and consumer followed by Japan while Canada is the world's leader in the trade of pulp and paper products , particularly, newsprint. Historically, the industry is one of the world's oldest, dating as far back as 105 A.D. when the art of paper-making from tree barks, discarded cloth and hemp was first invented by Ts'ai Lun of Lei-Yang, China (Abrams, 1963). As such the industry has, over the years, varied in importance within both the global manufacturing sector and the economies of leading regions in which it has come to be concentrated. Within the manufacturing sector, the pulp and paper industry is the most important by value added and employment generator of the forest products industries. Within the economies of leading regions such as Canada and the Scandinavian countries, the pulp and paper industry has historically been of great significance. In 1964, for example, pulp and paper products accounted for 20.4 percent of the total manufacturing output of Finland, 9.9 per cent of Norway, 9.8 per cent of Sweden and 8.2 per cent of Canada. In 1984, it was 16.5 per cent in Finland, 9.8 per cent in Sweden, 5.7 per cent in Norway and 7.4 per cent in Canada (Table 3.2). In terms of employment, it accounted for 7.1 per cent of all manufacturing employment in Canada, 11.1 per cent in Finland, 6.9 per cent in Sweden and 6.9 per cent in Norway in 1967. In 1981, it was 7 per cent in Canada, 2.2 per cent in Sweden and 9.2 per cent in Finland (Table 3.3). In the United States, it is the ninth manufacturing industry by size and importance. Even in countries such as Japan,

Table 3.2: **Percentage Share of Pulp And Paper Products in Total Manufacturing In Selected Countries And Years**

Country	1964	1974	1984
US	3.8	4.1	3.9
Canada	8.2	8.4	7.4
Sweden	9.8	11.2	9.8
Finland	20.4	19.2	16.5
Japan	3.9	3.7	3.0
FRG	2.6	3.7	2.4
Australia	3.3	2.8	2.8
New Zealand	4.8	5.6	6.6
Norway	9.9	8.5	5.7

Source: OECD, 1988, p. 206.

Table 3.3: **Percentage Share of Pulp And Paper Industry Employment of Total Manufacturing Employment in Selected Countries And Years**

Country	1967	1974	1981
US	3.5	3.5	3.4
Canada	7.1	7.3	7.0
Sweden	6.9	6.6	7.2
Finland	11.1	10.0	9.2†
Japan	3.2	2.9	2.7
FRG	2.6	2.4	2.3
Australia	2.8	2.4	2.2†
New Zealand	4.8	5.6	6.6
Norway	6.9	5.9	4.6†

† 1982 figure.
Sources: OECD, 1988, p. 207.

where pulp and paper products form only a small proportion of export trade, self-sufficiency in the industry not only saves the countries from large sums of foreign exchange which would be spent on imports of pulp and paper products but the industry also serves as a source of employment for thousands of people.

Industry Structure

The Production Structure

At the centre of the production structure is the mill. Historically, most mills often concentrate on the production of either pulp or paper. In recent decades, there has been a tendency towards *integrated mills*, in which logs are first brought to the wood mill for extraction of plywood and high value lumber. The residual chips are then transferred next door to be made into pulp which is then transferred to the paper section of the same plant complex to be made into paper (Smook, 1982). With reference to this trend, Gobbo (1981) shows that most mills in North America are partially or totally integrated on-site. In 1977 for example, 84 per cent of 117 paper mills in Canada were integrated while in the US it was 60 per cent. Japan has almost all its paper mills integrated (Macleod, 1985). The same applies to the Scandinavia. The region with the least number of integrated mills is the EEC. As Gobbo (1981) points out this structure of production thus gives North America and the Scandinavia a clear advantage in the production of such bulk grades of paper as newsprint.

Using data from 1972 and 1977 Gobbo (1981) observed that one of the most interesting features of the industry is the progressive increase in production capacities vis-a-vis a progressive reduction in the numbers of mills or plants, especially in the DMEs. Indeed Tables 3.4 and 3.5 show that the situation has not changed and even extend the observation from 1960 to the present. In addition, it is possible possible to confirm other observations made by Gobbo (1981) that in all areas, the average size of pulp mills is larger than that of paper mills (Tables 3.6 and 3.7). On the average, North America has the largest pulp mills in the world, while Norway as well as the main EEC countries, have smaller pulp mills (Tables 3.6). Between these two extremes are Finland and Sweden. In recent years, pulp mills in Brazil and the USSR have also attained large mills. In the paper sector Finland, particularly, has larger paper mills than those of North America. Paper mills in Canada are also large while in Japan and again in the main EEC countries the average size of

Table 3.4: **Number of Pulp Mills In Leading Pulp And Paper Countries, 1960-1985**

Country	1960	1965	1970	1975	1980	1985
France	53	54	47	42	30	24
FRG	-	-	53	28	39	37
Italy	65	65	157	158	70	25
Netherlands	5	41	14	15	7	6
UK	12	-	6	7	3	6
Finland	53	61	62	57	53	46
Norway	63	59	55	44	32	27
Sweden	82	121	95	89	72	56
Canada	41	44	39	37	37	34
US	451	276	313	334	225	225
Japan	191	135	166	109	70	65
USSR	46	55	58	105	60	57
Brazil	36	27	40	48	48	14

Source: Pulp And Paper International FactBook, 1987.

Table 3.5: **Number of Paper Mills In Leading Pulp And Paper Countries, 1960-1985**

Country	1960	1965	1970	1975	1980	1985
France	306	297	195	213	-	155
FRG	-	343	226	191	202	189
Italy	596	600	600	550	500	360
Netherlands	40	36	34	45	38	33
UK	225	219	187	147	135	96
Finland	41	40	45	48	46	46
Norway	69	45	42	36	30	26
Sweden	67	75	69	67	62	56
Canada	95	100	103	120	112	108
US	812	795	809	728	677	571
Japan	635	660	654	643	593	489
USSR	150	157	194	184	150	84
Brazil	62	75	130	179	160	164

Source: Pulp And Paper International FactBook, 1987.

paper mills are much smaller when compared with those of North America and the Scandinavia (Table 3.7).

Table 3.6: **Average Size of Pulp Mills ('000 Metric tons/Year) In Leading Pulp And Paper Countries, 1965-1985**

Country	1965	1975	1980	1985
France	-	48.5	66.3	90.4
FRG	-	61.1	51.6	57.9
Italy	-	8.3	16.6	
Finland	105.0	125.8	148.0	189.9
Norway	35.3	52.8	54.7	78.3
Sweden	62.8	121.3	145.3	171.1
Canada	352.6	585.3	581.7	681.1
US	122.2	126.4	209.4	231.5
Japan	46.4	109.1	179.6	184.8
USSR	-	80.5	174.7	211.4
Brazil	-	34.5	66.8	273.0

Source: Pulp And Paper International FactBook, 1987 and FAO Pulp And Paper Capacity Surveys, 1965, 1975, 1980 and 1985.

Table 3.7: **Average Size of Paper Mills ('000 Metric tons/Year) In Leading Pulp And Paper Countries, 1965-1985**

Country	1965	1975	1980	1985
France	11.6	27.6	-	38.9
FRG	-	40.8	42.7	54.2
Italy	-	8.7	11.5	16.5
Finland	91.3	126.1	136.8	175.8
Norway	-	44.4	55.0	70.6
Sweden	44.0	93.4	116.4	135.3
Canada	107.2	118.5	131.1	146.1
US	49.8	78.5	92.3	119.9
Japan	13.3	30.9	36.4	49.2
USSR	-	51.6	80.0	166.7
Brazil	-	13.7	23.2	28.6

Source: Pulp And Paper International FactBook, 1987 and FAO Pulp And Paper Capacity Surveys, 1965, 1975, 1980 and 1985.

The Main Pulp And Paper Firms

While the number of pulp and paper firms in the world can be counted in several thousands the largest firms account for important shares of global capacity, employment, investment and trade. Thus, we will limit ourselves to the very largest firm using the Pulp and Paper International's Top 100 annual survey, which has been conducted since 1974.

Table 3.8 shows the breakdown by country of origin of the top 100 hundred firms ranked by sales from 1974 to 1986 from which it can be seen that since 1974 the US has consistently accounted for not less than 30 per cent of the top 100 firms in the industry. Japan and Sweden are next after the US They accounted for between 11-12 per cent from 1974 to 1982 and for a more or lesser proportion thereafter. In contrast, Canada's share of the top 100 firms has gradually risen from the fifth place in 1974 to the second place in recent years, accounting for 12 per cent of the largest 100 firms. The domination of the US 1986, clearly portrayed by Table 3.9 which shows the breakdown of the companies according to rank and country. Seven out of the top 10 firms and 14 out of the top 20 were all US-based. Indeed since 1974, almost all the top 10 firms have been US-based.

Over the years pulp and paper firms have pursued several strategies of growth including horizontal and both forward and backward vertical integration. Many firms have also become, or have become part of conglomerates. The result is that for most of the very large firms, pulp and paper products constitute a lesser percentage of their annual total sales. This was particularly true of the Scandinavian firms. Thus of the 22 Scandinavian firms listed among the Top 100 firms in 1980, only 7 derived more than 80 per cent of their total sales from pulp and paper products. For 11 of them, pulp and paper products constituted between 50 and 80 per cent of their total sales (Table 3.10).[1]

In addition, a considerable number of the large pulp and paper firms have become international in character, even though the number of multinational firms in the real sense is still small. In 1976, for example, 50 per cent of the 34 US-based firms listed among the Top 100 firms had business operations in at least 2 countries (Table 3.11). The three most internationalised ones were Kimberly-Clark, which had operations in 22 countries, Scott Paper and Sonocco, with operations in 17 countries each. By 1986, this situation had not changed. On the whole, the Japanese firms seem

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1. The 1980 figure is used because the 1986 ranking was based on pulp and paper products only.

Table 3.8: **Countries of The 1974-1986 Top 100 Pulp And Paper Firms**

Country	1974	1976	1978	1980	1982	1984	1986
US	32	34	34	33	34	36	31
Japan	12	12	11	10	11	8	15
Sweden	11	12	11	11	11	10	8
Finland	9	7	7	10	8	10	8
Canada	7	6	8	8	10	12	10
France	7	7	6	5	5	4	4
FRG	6	5	5	4	4	3	6
UK	3	4	4	4	4	4	4
Australia	2	2	2	2	2	2	1
Belgium	2	1	2	1	1	1	0
Netherlands	2	2	3	2	1	2	2
Norway	2	2	2	2	1	1	0
New Zealand	1	1	1	2	2	2	2
South Africa	1	1	1	2	2	2	1
Italy	1	1	1	1	1	1	1
Brazil	0	0	1	1	1	1	1
Spain	1	1	0	0	0	0	0
Denmark	1	0	0	0	0	0	0
Turkey	0	1	1	1	0	0	0
Austria	0	1	0	0	0	0	2
Switzerland	0	0	1	1	0	0	2
Potugal	0	0	0	0	0	0	1
Chile	0	0	0	0	0	0	1

Source: Pulp & Paper International Top 100 Survey.

to be the most domestically oriented.

Diffuculties of obtaining suitable data often makes it impossible to obtain concentration ratios for the industry as a whole. However, a number of studies carried out indicate that in general, the concentration ratio of the industry is rather on the low side compared to the capital intensity of the industry. Gobbo (1981) found that the highest concentration was in the Scandianavia and also Japan and lower in North America. Arpan et al (1986) found that Japan still had a high concentration ratio. In particular it was higher in newsprint.

Table 3.9 **Ranking Of The Top 100 Pulp And Paper Firms By Country - 1986**

	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	Total
US	7	7	1	5	4	1	3	1	1	1	31
Japan	3	1	3	0	1	1	2	0	2	2	15
Canada	0	0	2	2	0	0	2	1	2	1	10
Sweden	0	1	1	1	1	1	1	1	1	0	8
Finland	0	0	1	1	1	0	1	3	1	0	8
France	0	0	0	0	2	2	0	0	0	0	4
FRG	0	0	2	0	0	1	0	1	1	1	6
UK	0	1	0	1	0	0	0	1	0	1	4
Australia	0	0	0	0	0	1	0	0	0	0	1
Netherlands	0	0	0	0	0	1	1	0	0	0	2
New Zealand	0	0	0	0	1	0	0	0	0	1	2
South Africa	0	0	0	0	0	0	0	1	0	0	1
Brazil	0	0	0	0	0	1	0	0	0	0	1
Italy	0	0	0	0	0	1	0	0	0	0	1
Switzerland	0	0	0	0	0	0	0	1	1	0	2
Portugal	0	0	0	0	0	0	0	0	1	0	1
Chile	0	0	0	0	0	0	0	0	0	1	1
Austria	0	0	0	0	0	0	0	0	0	2	2

Source: Pulp And Paper International Top 100 Surveys.

Table 3.10: **Percentage of Pulp And Paper Sales To Total Sales of Top 100 Firms In Selected Years**

	1976				1980				1986			
Firm/Country	10-50	51-80	81+	Total	10-50	51-80-	81+	Total	10-50-	51-80	81+	Total
US	4	8	19	27	6	8	16	30	4	9	18	31
Canada	1	5	-	6	-	5	2	7		4	6	10
Scandinavia	5	10	6	21	4	11	7	22	1	6	9	16
EEC	2	2	15	21	4	3	11	20	3	2	13	18
Japan	-	3	9	12	-	2	8	10	1	3	11	15
Others	-	-	2	2	-	-	2	2	1	2	6	9

Source: Pulp & Paper International Top 100 Survey, 1976, 1980, 1986

Table 3.11: **Internationalisation of The Top 100 Pulp And Paper Firms, 1976-1986**

	Number of Countries of Operations					
Year/Firm's Base	1	2	3-6	7-10	10+	Total
1976						
US	17	5	4	5	3	34
Canada	2	2	2	-	-	6
Scandinavia	6	7	7	2	-	22
EEC	6	8	3	2	1	20
Japan	9	3	-	-	-	12
Others	3	2	1	-	-	6
1980						
US	12	6	9	3	3	33
Canada	3	4	1	-	-	8
Scandinavia	8	5	8	1	1	23
EEC	3	8	7	1	1	17
Japan	5	4	1	-	-	10
Others	7	1	1	-	-	9
1986						
US	14	5	8	1	3	31
Canada	3	6	1	-	-	10
Scandinavia	4	2	8	-	2	16
EEC	9	2	6	1	1	19
Japan	12	1	2	-	-	15
Others	6	3	-	-	-	9

Source: Pulp And Paper International FactBook, 1987.

Factors Affecting Paper Demand, 1950–1988: Implications For Technology Choice

Past Consumption

According to FAO statistics, the world consumption of paper increased from 45.9 million metric tons in 1951 to 192.3 million metric tons in 1985, an increase in 319.3 per cent and an annual growth rate of 4 per cent. From 1951 to 1974, these consumption characteristics were particularly impressive: total consumption trippled and the annual growth rate was 5.7 per cent. After 1974, however, the consumption pattern was characterised by instability. In 1975, total consumption fell below that of the previous year and after picking up it fell again in 1982 below the previous year. The result is that the growth rate from 1975 to 1985 was 2.3 per cent per annum. By products, newsprint accounted for 29.8 per cent in 1951; by 1985 it was 12.5 per cent. Equivalent figures given in Table 3.12 for the other products indicate that the largest increase over the period occurred in printing and writing paper which gained an incredible 1293.6 per cent (from 3.6 million metric tons in 1951 to 50.7 million metric tons in 1985). This sector had the highest annual consumption growth rates: 6.7 per cent over the period with 9 per cent from 1951 to 1974. In contrast, the percentage change for newsprint between 1951 and 1985 was 222.3 per cent and the annual consumption growth rates were also the lowest in the paper sector. From 1951 to 1985, newsprint consumption grew by an annual rate of 3.3 per cent. From 1951 to 1974 it was 4.2 per cent, while from 1975 to 1985 it was 2.5 per cent. What factors have influenced this pattern of paper consumption and how have these factors affected technology choice in the pulp and paper industry?

The Basic Conditions of Paper demand

Newsprint and printing/writing paper are mainly used for communication purposes- newsprint for newspapers and printing and writing paper for magazines, catalogues, advertising material, books, office stationery and stationery for computers and photocopying in education (FAO, 1986). Paperboard is mainly used for packaging while the other paper grade-tissue- is used for household and sanitary purposes. The consumption of paper therefore depends on the state of communication and packaging and the competitive strength of paper relative to substitutes for these uses. In newsprint and printing/writing paper, these depend on the competition between the print media and audio-visual media while in paperboard, it depends on the competition between paperboard and other packaging materials such as plastics.

The demand structure of the two products, newsprint and printing and writing paper, however differs in some respects. The demand for newsprint tend to be price inelastic (OECD, 1988). Newsprint firms therefore tend to be strongly production-oriented. To ensure continued production

Table 3.12 **World Paper Consumption (In Million Metric Tons) 1951-1985**

Classification	1951	1960	1970	1974	1975	1980	1981	1982	1985
All Grades									
World	45.9	73.4	127.5	149.5	130.4	168.3	168.9	166.4	192.3
DME	40.1	61.1	102.7	119.8	100.7	128.9	129.1	125.0	144.4
DPE	1.7	4.3	9.5	12.4	11.5	18.0	18.1	18.4	20.8
CPE	3.1	-	-	16.8	17.3	21.4	21.5	21.9	27.1
Newsprint									
World	9.0	13.7	21.5	23.1	20.9	25.6	26.5	25.6	29.0
DME	8.0	12.0	17.8	19.2	17.0	20.8	21.1	20.5	23.4
DPE	0.5	1.2	1.8	2.0	1.9	2.7	3.1	2.9	3.1
CPE	0.7	0.8	1.9	2.0	2.0	2.1	2.2	2.1	2.5
Printing/Writing Paper									
World	3.6	13.7	27.1	33.1	27.7	40.4	40.6	41.1	50.7
DME	2.9	11.7	22.0	27.0	21.6	32.5	32.4	32.9	40.0
DPE	0.3	0.9	2.1	2.9	2.6	4.1	4.3	4.4	5.5
CPE	0.5	1.1	2.9	3.3	3.4	4.0	4.0	5.3	
Other Paper + Paperboard									
World	15.1	46.0	78.9	93.2	81.8	102.1	101.2	99.6	112.5
DME	18.8	37.4	62.3	73.7	62.1	75.5	75.5	72.9	81.0
DPE	1.0	2.2	5.6	7.5	7.0	11.1	10.7	11.1	12.2
CPE	1.6	6.0	10.4	12.0	12.7	15.3	15.3	15.6	19.4

Source: FAO Yearbook Of Forest Products.

of newspapers, in times of industrial action in the paper industry, large newspapers tend to have a large number of suppliers. Irrespective of the supplier , each roll of newsprint must be of identical quality so as to permit uniterrupted printing. This makes newsprint a highly standardised product. As a result it can be a disincentive, sometimes, for a newsprint firm to introduce quality changes since it may be standing alone in a market of unknown size or even does not exist (OECD, 1988). However, when quality changes occur and a newsprint firm comes under market pressure, the reaction can be very fast since it cannot afford to lose its competitiveness. As a result of these characteristics newsprint firms seek technological developments that will keep them in conformity with the market quality requirement and that will also reduce their cost of production (OECD, 1988).

In contrast, printing and writing paper and other grades like tissue tend to be market-oriented. The use of trade marks and advertising is very prominent in the media. Proprietary technological developments kept as company trade secrets, as well as a highly organised market intelligent structure and service are among the most important technological opportunities open to firms operating in this sector. Thus these market-oriented firms are more likely to follow an 'offensive' technological strategy than their counterparts in the production-oriented sector who are more likely to follow a 'defensive' technological strategy. Since 1950, certain factors have influenced the characteristic of these features pushing pulp and paper firms in both product-oriented and market-oriented sectors to demand new technologies. These factors include population growth, general economic growth and technological developments in paper-consuming industries and developments of subsitute products.

Population And General Economic Growth

The post-war drive for economic growth coupled with increasing population growth, expansion of education and the emergence of supermarkets, led to high demand for books, office stationary and packaging materials during the 1950s and the 1960s. Population growth was held to be the most single important factor driving the demand or consumption of paper and paperboard.

Growing nationalism in former European colonies with fast-growing populations and subsequent achievement of political independence which would open the way for stepping up mass education programmes therefore held high hopes for the pulp and paper industry. However at the end of the 1960s it became evidently clear that mere population growth without effective demand was not sufficient enough to support mass production of goods. In particular, it was realised that due to constraints imposed by slow economic growth and development consumption of paper and paper products in the developing countries, for example, demand and supply forecasts made by pulp and paper experts could not be fulfilled.

It became clear that economic growth and particularly growth in GNP was a more important determinant of demand for paper products than population growth. Yet it was found that even this depended on the type of product and the level of income being considered. A study conducted by the FAO (1967) established that for a given rate of income growth, consumption of paper and paperboard rose much faster in the developing countries than in the developed countries. However, while the expansion was initially at least usually in the cultural papers in the developing countries, in the developed countries it was in the industrial papers.

At any rate the worsening balance of payment difficulties, political instability, and energy crises during the 1970s pushed the already deteriorating economic conditions in a number of developing countries (particularly Africa) from bad to worse. The grand social programmes, including fee-free mass education, could no longer be supported. This meant that consumption of paper still continued to be generated from the developed countries . Thus, 89.2 per cent of the total consumption in 1951 was generated in the DMEs, 3.9 per cent in the DPEs and 6.9 per cent in the CPEs. By 1985, it was 75.1 per cent in DMEs, 10.8 per cent in DPEs and 14.1 per cent in the CPEs. From Table 3.12, it can be seen that the largest drop for the DMEs was in paper and paperboard followed by newsprint. In the DPEs and also the CPEs, the gain was in other paper and paperboard. Here too a number of events were taking place, which shifted the focus of the determinant of paper demand from income growth to technological developments outside the pulp and paper industry and development of substitute products.

Development of Substitute Products

Based on a study by Hurwitz (1984) FAO (1986) indicated that the information sector in the US reached 40 per cent of the total labour force in 1980, while in Japan it reached 30 per cent. Associated with this growth was the growth in information flow. For example, words made available by 17 public media grew at a rate of 8.4 per cent over 1960-1972 period. However, a greater part of this growth took place outside the print media. Thus the rate of growth in actual words 'attended to over the same period was a low of 3.2 per cent per annum. With particular reference to electronic media, the amount of words 'actually attended' increased from 60-70 per cent of the total words consumed while that from the print media fell from 30 to 18 per cent. In addition, expenditure for print media fell from 1950-1984 while that for television increased (Tables 3.13 and 3.14). Circulation of newspaper accordingly fell. In some countries such as France, indications have been given regarding replacing telephone directory with electronic system and video. In the paperboard subsector similar developments were taking place. The use of polythelene material for wrapping and transporting packages of food was found to be more cost-effective than paperboard. In Sweden for example, the FAO (1986) study showed that between 1965 and 1975, the use of plastic increased from 11 per cent to 21 per cent of consumption of packaging material while paperboard rose only 3 per cent from 45 to 48 per cent (Table 3.15).

Technological Developments In the End-Use Sector

Apart from this competition, the requirements in the end-use sectors were changing. With particular reference to newsprint, changing printing technology and the desire to reduce transportation and mailing costs on the part of publishers led to a demand for newsprint with lower basis weight (Table 3.16) which meant a reduction in the tonnage of newsprint consumed. Similarly the development and growth of the photocopier and the computer led to a demand for specialised papers such as punching cards and xeroxing paper materials. Finally, to survive the competition

Table 3.13 **Percentage Distribution Of Advertising Expenditure In The United States, 1950-84**

Media	1950	1960	1970	1980	1984
Television	3	14	18	21	23
Radio	11	6	7	7	7
Magazines	8	8	7	6	6
Newspapers	36	31	29	28	27
Direct mail	14	15	14	14	16
Miscellaneous	28	26	25	24	21

Source: FAO (1986) p.15

Table 3.14 **Percentage Distribution of Net Advertising Revenue In Canada, 1966-81**

Media	1966	1970	1975	1981
Television	12.4	13.1	13.7	17.1
Radio	9.8	10.7	10.7	10.8
Magazines	12.1	11.3	13.5	14.7
Newspapers	35.3	35.2	35.0	30.1
Direct mail	21.2	20.5	19.9	20.8
Miscellaneous	9.2	9.1	7.1	6.5

Source: P. Audley (1983) p. 5.

Table 3.15 **Percentage Changes In Packaging Consumption Expenditure In Sweden, 1965 - 1980**

Material	1965	1970	1975	1980
Paper and Paperboard	45	47	48	47
Plastics	11	15	21	24
Glass	7	7	5	4
Metal	19	19	18	17
Wood and others	18	12	8	8
Total value†	1425	2125	3300	4650

†: Million Swedish Kronor (1982 prices).
Source: FAO (1986) p.25

Table 3.16 **Selected Changes In Average Basis Weight Of Newsprint in Selected Countries, 1967 - 1984**

Country	1967				1984
Australia	52	49.7(74)	48.8(75)	48.1(83)	47.9
Canada	51.9	51.6(71)	49.3 (74)	48.5 (76)	48.4
China	51				51
FRG	52	50 (74)	49.5 (76)	48.4 (81)	48.3
Japan	51.8	50.4	48.7 (80)	47.5 (82)	46.6
New Zealand	52	48.7 (76)			48.6
Scandinavia	52.1	49.2 (74)	47.1 (77)	45.4 (81)	
UK	52	51.0 (71)	48.0 (74)	47.3 (81)	47.3
US	52.4	49.8 (82)	48.5 (78)		48.4
USSR	52	48.8 (82)			48.7

The figures in brackets are the years in which the changes occurred.
Source: FAO (1986) p.19.

from electronic media advertising, newspaper and magazine publishers began to demand higher quality paper grades, capable of full colour reproduction so that they could use colours in their adverts. From the pulp and paper firms' perspective the solution to the demand for more and higher quality paper lay in the paper machine. First, the quality of paper coming out of the machine had to be improved to meet the demands of the market and second, the speed of the machine had to be increased to boost production. These two needs initiated a demand for a new paper-making technology which as we shall see later, resulted in the twin-wire paper machine.

Factors Affecting Paper Supply, 1950–1988: Implications For Technology Choice

Past Production

According to FAO statistics, the world's output of pulp increased from 38.8 million metric tons in 1951 to 140.7 million metric tons in 1985 and at an annual growth rate of 3.3 per cent (Fig 3.13) In the paper sector, production increased from 46.3 million metric tons to 192.8 million metric tons, representing an increase of 316 per cent and an annual growth rate of 4.1 per cent. A detailed look at this pattern, however, shows that there were two distinctive parts to this growth, just as it was the case with paper demand and also pulp production (Fig 3.14). Thus from 1951 to 1974

FIG. 3.13 WORLD PULP PRODUCTION TREND, 1951-1985

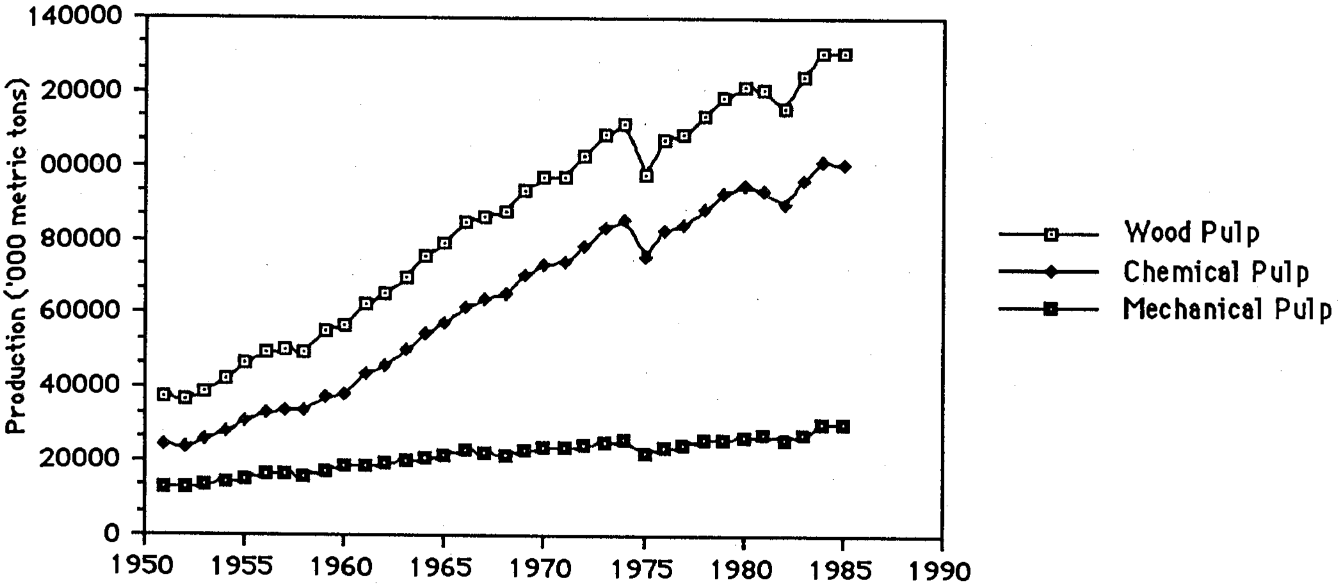
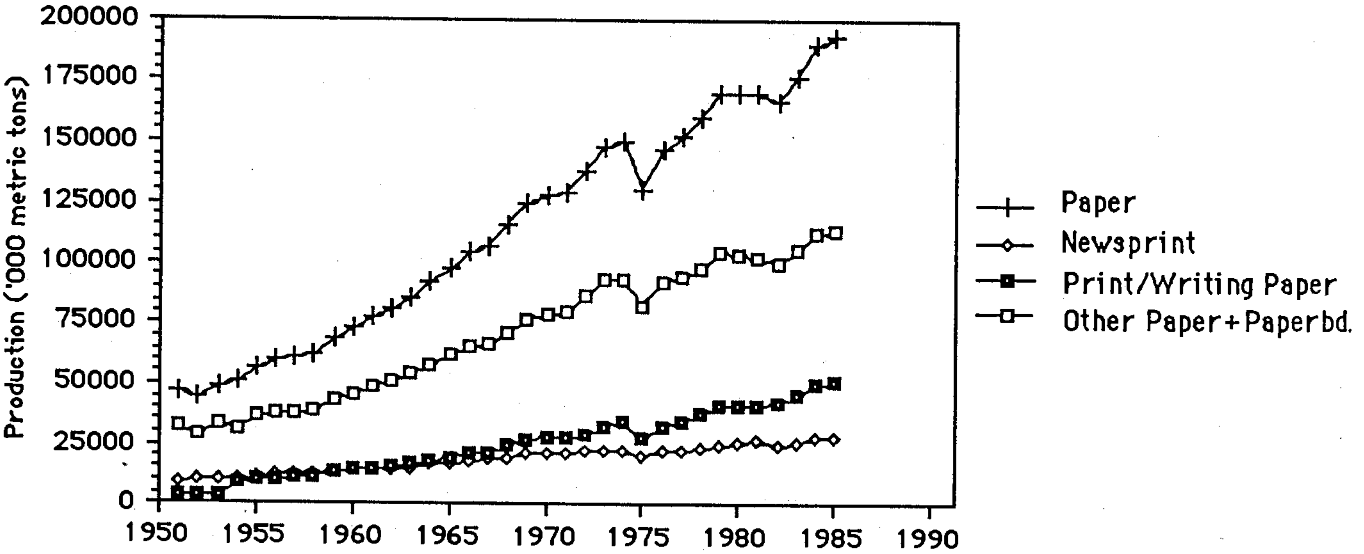


FIG. 3.14. WORLD PAPER PRODUCTION TRENDS, 1951-1985



Source: FAO Yearbook of Forest Products

was a period during which production grew steadily at an annual rate of 5.2 per cent After 1974, this pattern changed into an unstable one in which the growth rate made an average of 2.3 per cent per year. In particular, the 1975 production dropped to the 1971 level, the 1976 below that of 1973 while the 1977 production only managed to reach the level produced in 1973. It was not until 1978 that production reached the level attained in 1974. Similarly by the end of 1982, production level had fallen below the 1979 figure. With respect to specific paper grades, newsprint had the lowest growth rate in production over the period while printing and writing paper had the highest, followed by other paper and paperboard (Fig 3.14). In particular, the growth rates of printing and writing paper and other paper and paperboard production from 1951 to 1974 were 8.9 and 9.0 per cent respectively. The main factors that have affected these trends stem from the basic conditions of paper supply and the factors that cause these conditions to change.

The Basic Conditions for Paper Production

Paper is produced by draining water from an acqueos pulp suspension of a very low consistency. The technology involved , however, is quite complex and requires large sums of capital, fibre, skilled labour, energy, chemicals and water. The largest component of the capital requirement is the cost of the mill. In turn, this is determined by the machinery and equipment such as the digesters, concentrators, cleaners, liquor tanks, steam plants, presses, dryers and extensive piping (OECD, 1988). Considerable economies of scale is associated with the use of these equipment.

First, the unit cost of each component equipment decreases with the size of the equipment. In fact according to the OECD (1988) study cited above, this relation holds until an upper limit is reached, at which point construction material will no longer have the required strength or the process cannot be properly controlled. Even when such limits are reached, they are usually considered as temporary since new developments in material science can improve the strength of construction materials, and thus shift the upper limit. Second, the size of equipment also has effect on energy cost. An important component of the energy cost in the paper industry is heat loss. The main source of heat loss is through the surfaces of the vessels used. However, the relation between surface area and volume decreases exponentially with vessel size. This means that heat loss per processed unit decreases with increase size of the equipment used and so does the cost. Third, maintenance cost and labour cost are also affected by the size of equipment. Maintenance cost is proportional to the number of movable parts of the machine or equipment not the size. In turn, the number of movable parts is independent of the size of the equipment. As a result, maintenance cost is favourable to large units of equipment. Finally, in a process industry such as the pulp and paper industry, the essential role of labour is control function and is specifically in the operation of valves. Since the number of valves to be operated is independent of equipment size, labour cost per unit produce decreases with equipment size (Amsalem, 1983; OECD, 1988).

Economies of scale also have indirect effects on capital-labour ratio. Larger equipment have greater downtime cost. In addition, they have larger quantity of loading and unloading. As incentives to minimise downtime increases, so does the importance of performing loading and unloading operations as rapidly as possible (Amsalem, 1983). Loading and loading by more labour-intensive methods have a capacity unit of time which is limited by the workers physical access to the equipment. Once this limit is reached, it becomes necessary to resort to more automated methods of loading and unloading so as to prevent downtime from increasing proportionately with equipment size. Thus pressure valves of large reaction vessels operate under such a high pressure that they cannot be operated manually. Similarly , control valves of pipes that carry a ton of pulp slurry a minute cannot be closed by hand.

As a result of these advantages, the demand for equipment with bigger capacities and faster speed have been on the increase since 1950. Thus, in 1950 the maximum capacity of a Kamyr digester was about 100 tons per day. In 1983, it was about 1200 tons per day in 1983. A recovery furnace in 1950 could be built for about 200 tons of dry substance per day. In 1983, it was being built for about 2000 tons per day. Similarly, a newsprint machine in 1950 had a maximum speed of about 500m per minute. In 1983 it was about 1400m per minute and even more (Stockman, 1984). Since the size of these equipment determine the production capacity of the mill the strong tendency for bigger capacity equipment has also led to larger mill sizes, over the years. However, large mills also require large supplies of input, particularly fibre. The procurement of this usually involve important production costs such as drying, packing, storage, transport and relushing of pulp all of which can increase cost. To reduce these other production costs, pulp and paper operations have moved toward physical integration of pulp mills and paper mills on the same site. Just as raw material procurement problems arise with large production units, product marketing problems also come with large production units. These also induces forward integration into paper conversion activities as well as marketing and distribution sectors (FAO, 1967).

These do not mean that there are no limits at all to economies of scale in the paper industry. On the contrary, these economies of scale tend to be limited sometimes by the time period and the sector of operation. Thus mills built in a different time period may no longer enjoy economies of scale because the limits to the maximum size of equipment that existed at that time period may have shifted to a new upper limit. In addition, economies of scale in the mechanical pulp sector, for example, are limited by the maximum power that can be fed into a refiner. A large mechanical pulp mill therefore needs a series of refiners which in turn reduces the economies of scale. Also, specific local conditions such as market size, taste and fashion sometimes require small scale production units, which cannot fully utilize the economies of large scale production. Examples of these are such speciality papers as cigarette paper, electrical insulation papers and photographic papers (OECD, 1988). Usually, such market needs require different blends of different pulp orders and frequent changes on the paper machine that production in a large integrated mill set-up is just not suitable. Moreover, the general desire for large production units and joint demand for large supply of wood fibre, highly skilled labour, energy, and chemicals and cost involved in these imply that the pulp and paper industry involves a high capital cost. This means that changes affecting the supply conditions of factor inputs, and specifically those changes which raise the supply price of factor inputs, can substantially further raise the already high capital cost for the industry. Since 1950, important changes have taken place in the supply conditions of these inputs, particularly in the case of fibre resource, energy and chemicals, which directly and indirectly have led to the demand for new technologies. Attention will now focus on these.

The Role of Fibre Resource

From the early beginnings of the industry when rags were used as the basic raw material, and since the mid-19th century when wood fibre was first utilised, the availability of raw material has exerted a profound influence on the production pattern of the pulp and paper industry. It was the abundance of wood resources, mainly conifers of the temperate north, that gave the early advantage industrial development to such countries as Norway, Sweden, Finland, Canada and the United States. In recent decades, the growth of plantations and the increasing use of hardwoods and particularly tropical trees for pulping since the 1960s, for example, has not only increased the global production and trade levels but has also opened up a new competition from new regions, formerly considered to be marginal to the industry. A good example is Brazil, which has recently become an important competitor in the world pulp market. As indicated by Tables 3.17, 3.18 and 3.19 wood fibre is still the most important input of the industry. In 1983, for example, it accounted for 33 per cent of the manufacturing cost of bleached softwood kraft pulp in US south, 29.2 per cent in US North West, 31 per cent in BC coast region, 27.4 per cent in BC interior and 33.3 per cent in Ontario. In Finland, it was 45.8 per cent and in Sweden, 47.8 per cent (Table 3.17). In the paper sector, the situation was not different. In 1976, for example, it accounted for between 20 per cent and 29 per cent of the total manufacturing cost of newsprint even in the rich-wood resource regions of North America (Table 3.18). In 1983, it accounted for 18.3 per cent in the US south-east, 16.1 per cent in the US north-west, 18.8 per cent in BC coast, 28.5 per cent in Quebec, 30.3 per cent in Finland and 35.9 per cent in Sweden (Table 3.19). Indeed, the relative importance of fibre cost to the entire cost structure of the industry has dictated some fundamental production and business strategies in the industry. Thus, where fibre cost is relatively low, firms specialise in products

Table 3.17 **Manufacturing Cost (in US $ per ton) of Bleached Softwood Kraft Pulp In Selected Countries, 1982-1983**

Input	US South	US NW	B.C Coast	B.C Interior	Ontario	Finland	Sweden
Fibre	135 (33.0%)	122 (29.2%)	135 (31.0%)	107 (27.4%)	156 (33.3%)	174 (45.8%)	165 (47.8%)
Labour	44 (10.7)	48 (11.5)	60 (13.8)	49 (12.6)	60 (12.8)	42 (11.0)	34 (9.8)
Energy	49 (12.0)	54 (12.9)	51 (11.7)	44 (11.3)	51 (10.9)	19 (0.05)	18 (5.2)
Chemicals	45 (11.0)	38 (9.1)	42 (9.6)	43 (11.0)	70 (14.9)	37 (9.7)	34 (9.8)
Other Materials	43 (10.5)	41 (9.8)	45 (10.3)	39 (0.1)	30 (6.4)	28 (7.4)	30 (8.7)
Overhead	33 (8.1)	49 (11.7)	40 (9.2)	39 (0.1)	30 (9.0)	26 (6.8)	18 (5.2)
Depre. & Interest	60 (14.7)	65 (15.6)	63 (14.4)	69 (17.7)	59 (12.6)	54 (14.2)	46 (13.3)
Total	409	417	436	390	468	380	345

Source: De Silva (1988) p. 77

Table 3.18: **Newsprint Manufacturing Cost (in %), 1976**

	Fibre	Chemicals	Energy	Labour	Others
BC Coast	26	13	10	21	30
Canada (East)	29	10	11	20	30
U.S.A (South)	21	16	24	18	21
U.S.A (North-West)	20	15	18	19	28

Source: Gobbo, 1981 p. 58

Table 3.19 **Manufacturing Cost (in US $ per ton) of Newsprint In Selected Countries, 1982-1983**

Input	U.S South-East	U.S North West	B.C Coast	Quebec	Finland	Sweden
Fibre	76 (18.3%)	65 (16.1%)	77 (18.8%)	112 (28.5%)	112 (30.3%)	122 (35.9%)
Labour	74 (17.8)	88 (21.8)	92 (22.5)	87 (22.1)	56 (15.1)	47 (13.8)
Energy	110 (26.5)	100 (24.8)	72 (17.6)	60 (15.3)	79 (21.3)	67 (19.7)
Chemicals	17(0.04)	17 (0.04)	11 (2.7)	10 (2.5)	10 (2.7)	11 (3.2)
Other Materials	46 (11.0)	43 (10.7)	60 (14.7)	44 (11.2)	45 (12.2)	40 (11.8)
Overhead	38 (0.1)	28 (0.1)	47 (11.5)	44 (11.2)	26 (7.0)	17 (5.0)
Depre. & Interest	54 (13.0)	62 (15.4)	50 (12.2)	36 (9.2)	42 (11.3)	36 (10.6)
Total	415	403	409	393	370	340

Source: De Silva (1988) p. 76

requiring most fibre, namely the low or bulk grades. Where fibre cost is high, firms specialise in either products that can be most suitably produced with recycled material such as newsprint and paperboard, or in high value-added products that use less amount of fibre. In the same vein, concerns about current and perceived supply of wood fibre has always necessitated the search for new sources of supply.

During the 1960s and the 1970s dwindling forest resources, environmental and other concerns, led to a number of government policies aimed at regulating the use of forest in all the major pulp and paper countries. In the US several acts were passed, such as the Wilderness Act of 1964 and the Endangered Species Act in 1973. The perceived impact of these acts on the wood supply situation facing the US pulp and paper industry was such that the American Pulpwood Association had to raise strong oppositions to the Acts. For example, since the Wilderness Act was passed in 1964, the US Congress continued to designate wilderness areas that the American Pulpwood Association became alarmed at the rate at which this was being done. In 1980, the hope for a comprehensive national bill was abandoned and this opened the way for numerous bills at the state level (Arpan, et al, 1986). In Canada, government reassessment of its timber resources took place in 1973 and again in 1976 with the view to estimating the potential impact of the forest management practice on growth and yield. In 1975, the Quebec government began a buy back of major public forest concessions from private hands. In British Columbia, the Forestry Ministry freed chips from an old allocation system in April 1980 and forced pulp mills to compete against each other on the open market consequently causing an increase in chip price. In Sweden fear of diminishing forest resources led to a comprehensive bill on a search for balance among forestry, recreation and location of pulp mills in 1972. Even though the Joint Committee of the Swedish Forest Industries had co-operated with the Government in passing the bill and had indicated its future requirements, in October, 1973 the Swedish government temporarily halted all mill expansions when the Swedish pulp and paper industry was about to launch an active expansion (Arpan, et al 1986). In Finland, the Government embarked on an ambitious forestation programmes called MERA I and

II as Finland began to buy raw timber from the USSR. The programme, involving the provision of tax incentives to ensure better forest management, was aimed at draining and fertilising an estimated 9 million hectares of marshland.

The use of wastepapers which had been practised in some countries such as Japan since the 1950s also began to receive more support from other national governments, partly as a result of the dwindling wood fibre resource and partly as a result of the environmental issues . More concrete steps to increase *recycling of wastepaper* were taken. Sweden passed a law in 1975 making municipal authorities responsible for separate collections from household of paper and other waste with considerable investment in recycling following later. France launched a campaign of subsidies aimed at encouraging recycling of paper in 1976. In UK the government provided grants to the tune of £23 million to increase capital investment in recycling in 1977. In Japan similar concerns were expressed (Arpan et al, 1986).

Alongside these developments, a number of pulp and paper firms began to look for more sources of wood fibre outside their own national boundaries. Examples of these include the acquisition of forest lands by mostly Western European, Scandinavian and a few Japanese firms in Canada during the 1960s; American and a few Scandinavian and Japanese firms in Brazil during the 1970s and mainly Japanese firms in South East Asia.

These developments had significant impact on the demand for new pulp and paper technologies because, apart from setting the stage for a new competitive environment, international investments by firms to own fibre resources in other countries were not always successful for the firms involved. Examples in this case being the rather costly venture of Eurocan, a Finnish firm which moved to locate in British Columbia, Canada in the early 1970s. Other examples include the Japanese ventures in Latin America (Arpan, et al 1986). In the final analysis, the need to broaden the fibre base to include other materials such as bagasse, saw dust, wood chips, waste paper and hardwoods provided a most promising option to investigate. The demand for new technologies to open up these areas partially led to such developments as TMP and other mechanical pulping processes and de-inking processes for recycled offset papers (Evans, 1978).

The Role of Other Inputs

The possibility for substituting labour with capital in the pulp and paper industry often varies with sector. In the newsprint sector for example, new technological developments since 1950 has not had much adverse impact on labour. However, in other areas of the production line, particularly in the finishing room and the overall process control, there has been important substitution of capital for jobs that were formally performed manually. In spite of the differences, labour cost is still substantial even in relatively low-labour cost regions as the US. In 1976, for example, labour cost was the most important after wood in the production of newsprint, accounting for 21 per cent of the total manufacturing costs in an integrated mill in the British Columbia coastal region (Table 3.18). In eastern Canada, it was 20 per cent in the US north-west it was 19 per cent. In 1982-83, apart from Canada where it was still the most important, labour cost was the third most important cost (Table 3.19). Apart from the high labour cost, labour relations such as industrial strikes prevalent in places like North America have on one time or the other affected the production levels considerably.

Table 3.17 also shows that in 1983 for example, energy cost ranged from as low as 0.05 per cent of the manufacturing cost of bleached softwood kraft pulp in Finland to a high of 12.9 per cent in the US north-west. In the newsprint the range was from 15.3 per cent in Quebec to 26.5 per cent in the US south-east (Table 3.18). Thus in recent years, energy cost has become the most important cost element in newsprint manufacture in the US. According to Westerberg (1988), the period from 1950 to 1970 was characterised by a steady fuel costs and decreasing power costs. As a result the temptation to install low pressure gas and oil fired boilers was great. The only major pulp and paper producing regions that were conscious of energy conservation were Finland and Sweden and this, according to Westerberg (1988), was due to the two countries past experiences with fuel shortages particularly during the World War II. The result is that the oil shock of the mid-1970s had a devastating effect on global paper production and to a very large extent contributed to the fall in the production of paper after 1974 and the subsequent production instability, that has already been alluded to. Thus the percentage fall in production was highest in the largest consumer sectors such as mechanical pulp and newsprint. The need for energy-efficient methods became important and it was out of these that new mechanical pulping processes and shorter bleaching methods were developed.

Clearly evident also is the substantial use of chemicals and chemical products. Gobbo (1981) estimated that a ton of paper finally produced will require about 0.25 ton of chemical additives. In actual fact, the industry is the principal consumer of such chemicals as allum, chlorate, and sodium sulphate. As indicated by Table 3.18 chemical cost in newsprint manufacture in the coast region of British Columbia was even higher than energy in 1976. Indeed, the chemical industry has a substantial research and development investments in the pulp and paper industry. In addition to the use of chemicals, the pulp and paper industry is a large consumer of water. According to Gobbo (1981), an OECD study in the 1970s estimated that the annual water consumption by a group of 400 pulp and paper firms was approximately equivalent to the consumption of 100 cities of one million inhabitants each.

The use of large amount of chemicals and water make the pulp and paper industry one of the big agents of water and air pollution. The public concern about water pollution control reached a head in the late 1960s and early 1970s and pollution control regulations were enacted in all the major pulp and paper producing countries, particularly in North America and Japan where no stringent water pollution control measures existed. The immediate impact of these regulations was to raise the capital cost for the industry. In the US for example, the initial cost of complying with these regulations amounted to about $1,110 million which was about 50 per cent of the total capital expenditure in the industry but thereafter it declined to around 10 or 11 per cent (Arpan, et al, 1986). In Canada, environmental spending in 1977 averaged about 13 or 14 per cent of the total capital spending and thereafter except for 16 per cent in 1978 and 12 per cent in 1980. In Japan, the percentage of total capital spending devoted to pollution control, was less than 16 per cent in 1970. However, the proportion rose to between 18 and 25 per cent annually between 1972 and 1976 dropping to 4 per cent in 1978 and thereafter. In Europe similar effects were felt as pulp and paper companies sought to meet the demands of pollution laws.

As already pointed out, the pulp and paper industry is by nature capital intensive. Existence of economies of scale in the production process has the potential of pushing this high cost further. This means when factor inputs also become expensive, the operating cost can become very expensive. Thus the combined impact of the overcapacity that resulted in the 1950 expansion wave, the dwindling fibre resources in Europe and Japan in the 1960s, the energy crises of the 1970s and also the enviromental issues was to raise the production cost for the industry. These developments generated a number of events, two of which had very significant impact on the demand for new technologies and thus technology choices by pulp and paper firms.

First, national governments in all the major pulp and paper producing regions had to embark on 'rescue missions' which, among other programmes, involved capital grants to their respective national industries. In April, 1976 the UK government proposed to make £25 million to paper producers for capital investment over the next five years. In Sweden pulp and paper companies were allowed to keep a tax-free part of their profits in good years against bad years. When the recession set in, this contingency resource could not meet all the needs of the companies and the Swedish government had to make large amounts of direct grants to save the companies. In 1977 and 1978, the French government made available a partially subsidized loan of $73 million and $32 million to the two larger companies and another $65 million to be split by three smaller ones. The Dutch government made available $1.5 million to a boxplant in the northern part of the country. Similarly, in 1980, the Belgium government agreed to pay $50 million of the debts of Intermills, the country's leading producer of paper. In addition the government guaranteed new debt of over $30 million. In Canada, almost all major mill constructions between 1973 and 1976 received assistance from both the provincial and federal governments. In 1978, the Quebec provincial government announced a $450 million to the Quebec pulp and paper industry over a 5-year period. In the same year, the Ontario government announced a similar programme for Ontario. In 1979, the federal government presented its *Pulp and Paper Modernisation Programme*, a $235 million grants programme as part of the national development policy assistance to the forest products industry. Subsequently, cost-sharing agreements were signed with the governments of Ontario, Quebec, New Brunswick, Nova Scotia and Newfoundland and between April, 1979 and April, 1985, approximately $544 million was spent by the federal and provincial governments to assist the industry (de Silva, 1988). In Canada, as elsewhere, these grants were for the specific purposes of modernising the production processes, pollution abatement and efficient utilisation of energy.

Second, pulp and paper firms adopted some cost minimisation strategies most of which had strong technological components. Led by the Scandinavians, European firms resorted to what came to be known as *structural rationalisation* . Basically this strategy consisted of deliberate acts to cut down production cost and at the same time maintaining competitive ablility in the international market. Practically, the strategy consisted of three tools: first, production levels were reduced so as to remove the overcapacity in the industry; second, mills with old and inefficient machines were shut down and third, existing mills were modernised. In Norway, where the impact of the overcapacity and rising production cost was most severely felt, the firms decided not to open up any more new mills so as to make the existing ones more efficient. In addition, over 60 per cent of the mechanical pulp, 40 per cent of chemical pulp and 70 per cent of paper capacities in existence in 1960s had been shut down by 1979. In 1970 alone, Sweden shut down 41 pulp and 11 paper mills. By 1985, the number of pulp mills had dropped from 166 in 1970 to 112. In the Federal Republic of Germany (FRG), the number of paper and board mills grew by 68 to 394 between 1950 and 1960. However, between 1960 and 1970, it fell by 63 thus returning to the 1950 level (Fischer, 1971 p. 49). By 1984 the number was down to 218. In North America, even though firms continued to expand production facilities contrary to the hold-ups in Europe, some mills were shut down because of inefficiency in both Canada and the US. In the US 84 paper and paperboard mills, involving 290 paper machines were shut down between 1970 and 1980 (Lowe, 1981). These machine shut-downs were replaced by a smaller number of new and bigger machines. Thus between 1976 and 1980 for example, about 347 paper and board machines were shut down in the OECD countries (OECD, 1982). These had a total combined capacity of 8.4 million tons of paper a year. In their place 109 new machines were installed which had a total combined capacity of 8.3 million tons of paper a year (Tables 3.20 and 3.21).

The need to cut down production cost as result of rising cost of factor inputs such as energy, labour and chemicals and pollution control pushed pulp and paper firms to seek production processes that are particularly labour-saving, energy-saving and even chemical-saving. Mill-wide process automation, and increasing mechanisation of jobs formerly undertaken by unskilled workers such as inspection, counting and ream packaging became necessary to partially reduce labour cost. Rising energy cost needed new mechanical pulping processes that will be energy-efficient while rising concern about pollution of the environment and the cost involved in cleaning it up demanded new bleaching processes that would be low in the discharge of toxic elements. Finally, the shut down of old and inefficient machines vis-a-vis the modernisation of existing ones required faster and bigger paper machines, that will make it possible to increase the production capacity in a smaller number of mills. As we have already seen these needs contributed to the development and introduction of mill-wide process automation, such pulping processes as CTMP, improved bleaching processes like oxygen bleaching and finally the twin-wire paper machine.

Table 3.20 **New And Shut Down Paper And Board Machines By Grade For Certain OECD Countries, 1976-1980***

Grade	New Paper And Board Machines			Shut Down Paper And Board Machines		
	No. of Units	Avge. Capacity ('000 tonness)	Total Capacity ('000 tonnes)	No. of Units	Avge. Capacity ('000 tonnes)	Total Capacity ('000 tonnes)
Newsprint	17	149	2538	18	44	792
Print and Writing, wood containing†	7	83	583	36	19	691
Print and Writing, woodfree††	25	70	1742	73	12	844
Tissue	21	27	568	36	8	276
Other Paper	21	83	1738	149	18	2635
Paperboard	18	60	1072	135	23	3094
Total	109	76	8241	447	19	8332

* The countries represented in the Table are Canada, US, Japan, United Kingdom, France, Finland, Norway and Sweden.
† The furnish for this printing and writing paper grade includes mechanical pulp
††: The furnish of the printing and writing paper grade consists of only chemical pulp.
Source: OECD (1982) p. 26

Table 3.21 **New And Shut Down Paper And Board Machines By Selected OECD Countries, 1976-1980**

Country	New Paper And Board Machines			Shut Down Paper And Board Machines		
	No. of Units	Avge. Capacity ('000 tonness)	Total Capacity ('000 tonnes)	No. of Units	Avge. Capacity ('000 tonnes)	Total Capacity ('000 tonnes)
Canada	4	80	320	8	71	570
United States	37	108	3984	143	22	3081
Japan	34	55	1884	51	17	857
France	13	24	313	90	7	619
FRG	15	36	544	73	8	553
United Kingdom	6	26	157	61	18	1070
Finland	5	114	570	19	22	409
Norway	2	112	225	25	10	248
Sweden	8	99	791	49	11	5267
Total	124	71	8788	520	15	7933

Source: OECD (1982) p. 27

Paper Trade And Market-Related Issues

Past Trends

Since 1950, between 13 and 18 per cent of the total wood pulp produced and consumed every year had entered the world pulp trade. With respect to the paper sector, the proportion has been consistently around 15 per cent. Both pulp imports and exports increased by three-and-a-half times of their 1951 level by 1985 with annual growth rates of 4.0 per cent in both areas, chemical pulp become increasingly important over the years. In the paper sector, trade increased more than fourfolds over the period and at an average growth rate of 4.8 per cent. Thus the total volume of paper traded increased from 8.1 miilion metric tons in 1951 to 40.3 million metric tons in 1985 (Table 3.22). Newsprint remained the most important trading commodity until 1980 when the volume traded was exceeded by that of other paper and paperboard grade. Printing and writing paper showed the largest improvement. The pattern of paper trade was similar to those of production and consumption. After a period of steady growth, the export rate began to fall after 1974 for all the products, with the largest fall occurring in other paper and paperboard.

Historically, the pattern of paper trade has generally concentrated on three main regions: the European region, the North American region and the Pacific region. In newsprint, in particular, an overwhelming majority of the trade has been very much confined to these regions. In the European region, the main exporters are the Scandinavian countries with the EEC as the main importers. In the North American region Canada dominates the export trade, with the US as the major importer. In the Pacific region, most of the trade has centred on Japan.

Thus in 1951, 95.2 per cent of Canada's newsprint export went to the US with only 2 per cent going to Europe and the remaining 2.8 per cent to the rest of the world. In 1985, the US still accounted for 84 per cent of Canada's total newsprint exports. In contrast, the Scandinavian countries went from a relatively more diversified trade pattern in 1951 to a less diversified one in 1985 (Fig 3.15). Thus in 1951 only 32.2 per cent of Finland's export went to Europe. In 1985, it was

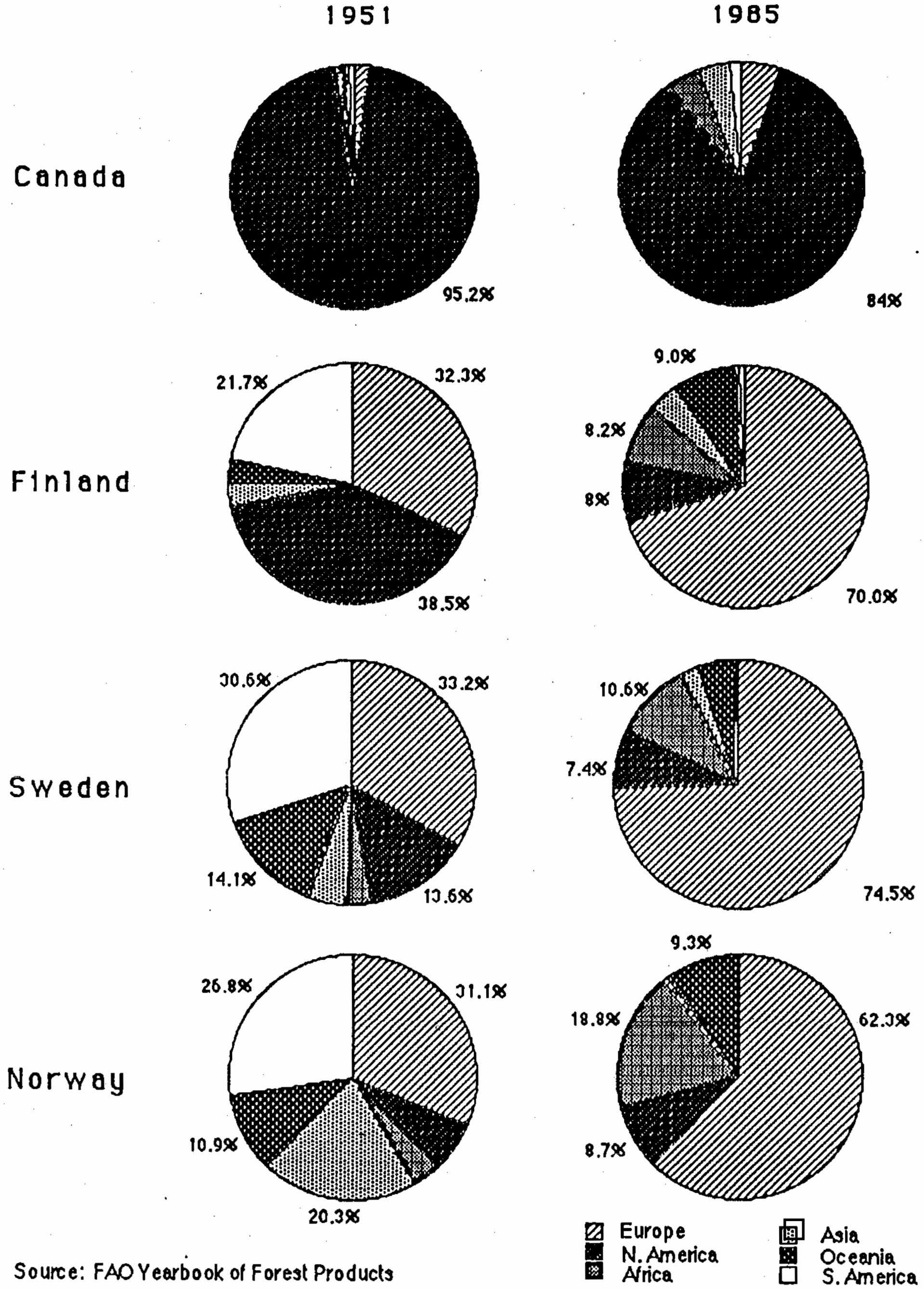
Table 3.22 **World Paper Exports (In Million Metric Tons) 1951-1985**

Classification	1951	1960	1970	1974	1975	1980	1981	1982	1985
All Grades									
World	8.1	12.0	23.4	30.1	23.1	35.0	35.4	33.6	40.3
DME	8.1	11.6	22.0	28.2	21.4	32.4	32.6	31.1	37.2
DPE	0.0	0.1	0.2	0.4	0.3	0.7	0.8	0.7	1.1
CPE	N/A	0.3	1.2	1.4	1.4	1.9	1.9	1.9	1.9
Newsprint									
World	5.6	7.8	10.6	11.5	9.4	12.3	12.9	11.5	13.4
DME	5.6	7.3	10.2	11.1	9.0	11.8	12.4	11.0	12.8
DPE	0.1	0.003	0.01	0.1	0.1	0.1	0.1	0.1	0.2
CPE	N.A	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.4
Printing/Writing Paper									
World	0.5	1.1	3.5	5.7	4.4	7.2	7.5	7.6	9.7
DME	0.4	0.9	5.4	4.1	4.1	6.7	7.0	7.2	9.2
DPE	0.02	0.03	0.04	0.1	0.1	0.3	0.3	0.3	0.3
CPE	N/A	0.1	0.01	0.2	0.2	0.2	0.2	0.2	
Other Paper + Paperboard									
World	2.1	3.6	9.2	12.8	9.3	15.3	14.9	14.5	17.1
DME	2.0	3.4	8.3	11.7	8.2	13.9	13.2	12.9	15.2
DPE	0.02	0.03	0.1	0.2	0.1	0.3	0.4	0.3	0.6
CPE	0.05	0.1	0.7	0.8	0.9	1.3	1.3	1.3	1.3

Source: FAO Yearbook Of Forest Products.

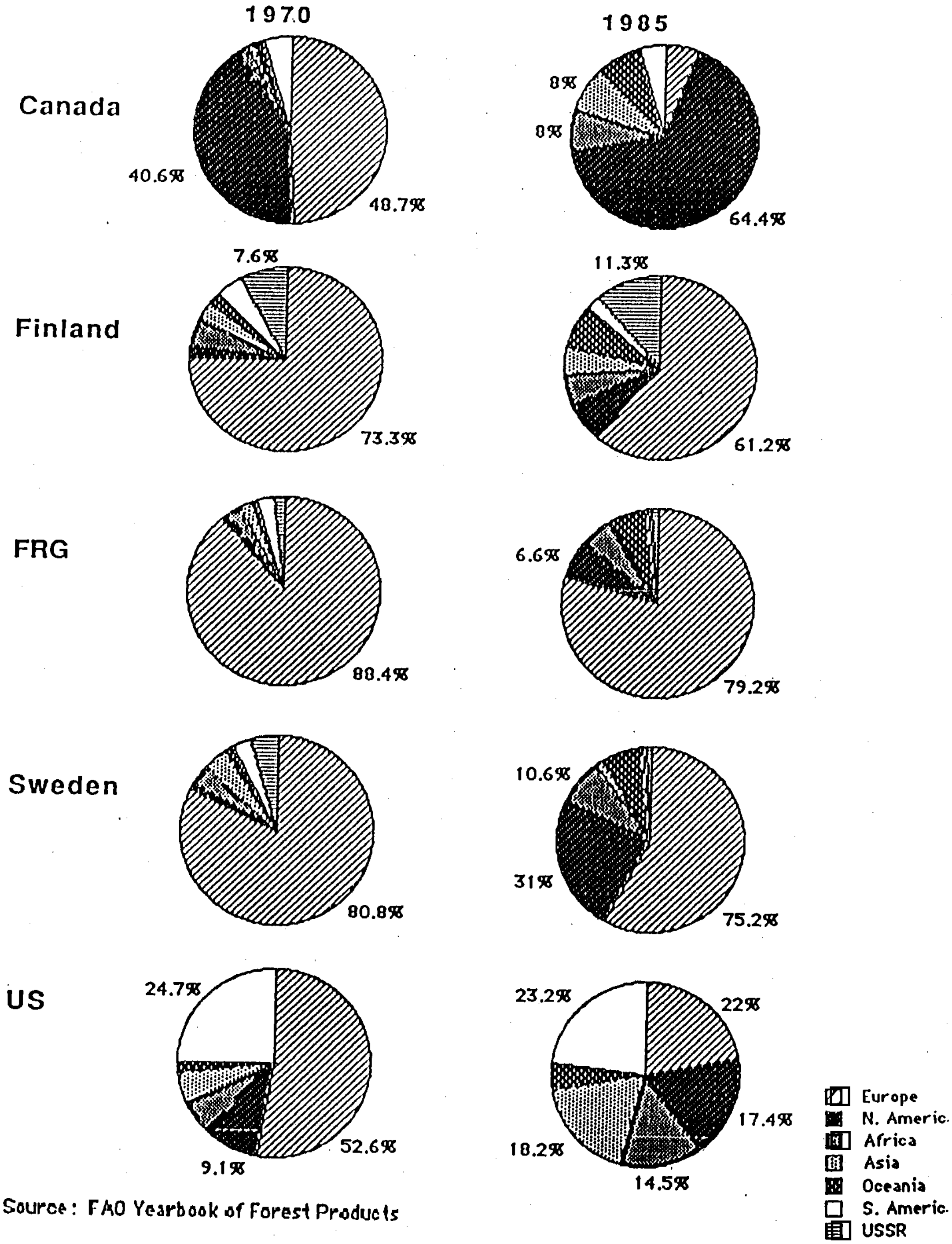
FIG. 3.15: DIRECTION OF PAPER TRADE IN SELECTED

Newsprint



Source: FAO Yearbook of Forest Products

Other Paper Grades



Source : FAO Yearbook of Forest Products

70.0 per cent. Equivalent statistics for Sweden were 33.2 per cent in 1951 and 74.5 per cent in 1985. For Norway, it was 31.1 per cent in 1951 and 62.3 per cent in 1985.

In the other paper and paperboard grades, similar strategies grades similar strategies have been pursued, by major exporting countries, particularly the Scandinavian countries and FRG. Thus, available FAO statistics indicate that in 1970, 79.4 per cent of Sweden's, 69.6 per cent of Finland's and 84.3 per cent of FRG's exports were all directed at Europe. By 1985, the situation had not changed. Indeed the only exporting nation that showed a relatively higher degree of diversification of market outlets was the US In 1970 52.6 per cent went to Europe; by 1985 this had reduced to 22 per cent with Latin America receiving 23.2 per cent (Fig 3.15). Most of this trade has been in linerboard. Trade in printing and writing paper has been on the increase and have gone beyond the traditional trading boundaries referred to above. Of particular importance is the trade between the European nations and the developing countries of Asia and also the US (Aurell and Poyry, 1988).

In such a highly regionalised pattern, when government and intergovernmental policies 'sever' former trade relations, the potential to diversify market outlets or even maintain the status quo without resorting to such technology-based strategies as product differentiation and value-added varieties is very limited. Indeed, in the pulp and paper industry this situation has been demonstrated due to government and intergovernment trade and fiscal policy instruments such as tariffs and quotas, anti-dumping accusations, and exchange rate management.

Tariffs And Quotas

The most significant example of the use of tariffs in the pulp and paper industry has been by the European Economic Community (EEC). The formation of EEC and the European Free Trade Area (EFTA) in 1957 and 1960, respectively and subsequent removal of tariff barriers among EEC countries and the establishment of a common tariff barrier by 1968 and quotas against non-EEC member nations changed greatly former trade relations in Europe and the developed world. The fact that the leading pulp and paper exporting nations of Europe, the Scandinavian countries were not members of EEC and had joined EFTA made this new trade relations more significant.

In 1972, the EEC signed an agreement with the EFTA nations by which there was going to be a gradual increase in quotas and decrease in tariffs from 1973 until January, 1984 when the tariff would be abolished. Instead of applying the common external tariffs of 12 per cent applicable to all non-EEC members, EEC agreed to give EFTA members a preferential tariff barrier of 10.5 per cent.[2] Based on the estimation that EEC demand was going to increase by 5 per cent every year, ceilings set for EFTA products were to rise by 5 per cent every year. By 1975, imports from the EFTA had become a very sensitive issue and the EEC estimates had to be seriously revised. At the end of 1975, EEC froze the import ceiling on paper products for 1976 at the 1975 levels. More ceilings were recommended in 1978 on 8 out of the 18 pulp and paper imports. In 1978 the EEC presented a compromise with five ceilings remaining frozen for the following year. Not willing to undermine the initial spirit of the agreement with the EFTA, the EEC resisted the continued pressure from national industries and CEPAC for further ceilings in 1977 and 1981. [3] Discussion in mid-1977 between EFTA and EEC for changes in the ceiling broke down because while Sweden and Austria were pressing for an increase of the ceiling quota from 5 per cent to 8 per cent , a number of EEC nations were asking for a decrease from 5 per cent to between 2.5 and 3 per cent.

Price-Fixing And Anti-Dumping Arrangements

Closely related to tariffs and quotas are attempts by some national governments and inter-govermental organisations to make the industry more competitive by attacking *international price-fixing and anti-dumping arrangements*. For example, in 1977 the French Pulp and Paper Confederation, responsible for 75 per cent of all the kraftliner produced in the EEC, lodged a complaint with the EEC against the US kraftliner producers for dumping in the European market and

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2. This was agreed upon by separate agreements with Sweden, Norway, Finland and Austria.

3. CEPAC is the EEC-wide organisation for paper producers.

thus harming the EEC industry. The charge was that US producers had not adequately accounted for transportation and handling costs in their prices quoted to European buyers. After the charge had been investigated, an antidumping duty was imposed on the US kraftliner exports to Europe in March 1978 and a voluntary consent were obtained from Sweden, Finland, Portugal, Austria and Canada to abide by the same conditions so as to avoid being investigated. In January, 1978 the French again accused the US and Canadian pulp producers of selling pulp in Europe at prices which did not take account of transportation and insurance costs of $42 per ton. However, this accusation failed to gain support because of the possible impact it was going to have on very strong interest groups within EEC itself. Again in 1982, the French government attempted to establish a case against US kraftliner exporters. In spite of the split among EEC members on this issue, EEC officials set higher minimum prices for kraftliner in 1983 after a fact-finding visit to the US, Canada, Sweden, Finland, Austria, Portugal and the USSR.

Exchange Rate Management

Exchange rates of national currencies arising directly and indirectly from national government policies have also affected trade in the industry in the past. Directly, national governments' attempts to ease off domestic economic pressures like growing trade deficit, rising unemployment and demand to save imperilled export-oriented industries in the country have resulted in devaluation of national currencies which in turn have made the exports of the country concerned, cheaper than those of its competitors. In 1968, for example, Finland devalued its currency by 31 per cent due to a persistent trade deficit since 1964. In the same year Britain, the then world's biggest wood pulp and second biggest import paper market, devalued the pound sterling by 14.2 per cent (from $2.80 to $2.40). The Scandinavian countries devalued their currencies again in the 1970s and in 1982. The 1982 devaluations were particularly controversial. Led by the devaluation of the Swedish kroner by 16 per cent, the Finnish government followed suit on the pretext that it had to maintain an equal currency alignment with its major trading partner. It turned out that these devaluations came at the time when, as a result of falling demand in Europe and beginning of falling prices in the US, members of EEC were putting pressure on Sweden for lower prices. The actions of the Scandinavian countries were therefore interpreted as deliberate attempts to capture most of the market. In retaliation, EEC raised the tariffs on most grades of Swedish paper from an average of about 4 per cent to nearly 11 per cent (Arpan et al, 1986).

Integration And Diversification Policies

Partly as a result of the difficulties brought by tariff barriers and other national policies that impinge on trade and partly as result of the need to survive in a rapidly changing world of the general manufacturing sector pulp and paper firms embarked on a number of growth, marketing and production strategies. First, a number of firms embarked on horizontal integration strategies through mergers, sale and acquisitions within their home countries and also abroad. In particular, to circumvent the problem of the common tariff barrier and frequent anti-dumping accusations by EEC members, a number of pulp and paper firms in non-EEC member nations , particularly North America and Scandinavia, began to find market holds within the EEC. Using data from Jaako Poyry, Gobbo (1981) indicates that this trend attained significant proportions after 1975. In 1972 for example, American or Canadian firms controlled wholly or partially about 2 million tons of European capacity of paper and paper products. By 1977 this had risen to 3.8 million tons. Within the EEC, paper production capacity controlled by US firms reached 11 per cent of the 1977 total while the Scandinavian firms controlled another 6 per cent. Within North America itself a number of firms on both sides of the 49th parallel crossed over to locate outside home economies for market and raw material reasons. In addition, a number of mergers and acquisitions took place among major pulp and paper firms in the US, Canada, Japan, Sweden and Finland. In Canada, this included the acquisition of MacMillan-Bloedel, Repap, Consolidated-Bathurst and mergers like Abitibi-Price, while in the US, it included the acquisitions by St. Regis, Fort Howard, Boise Cascade, and James River Corporation.

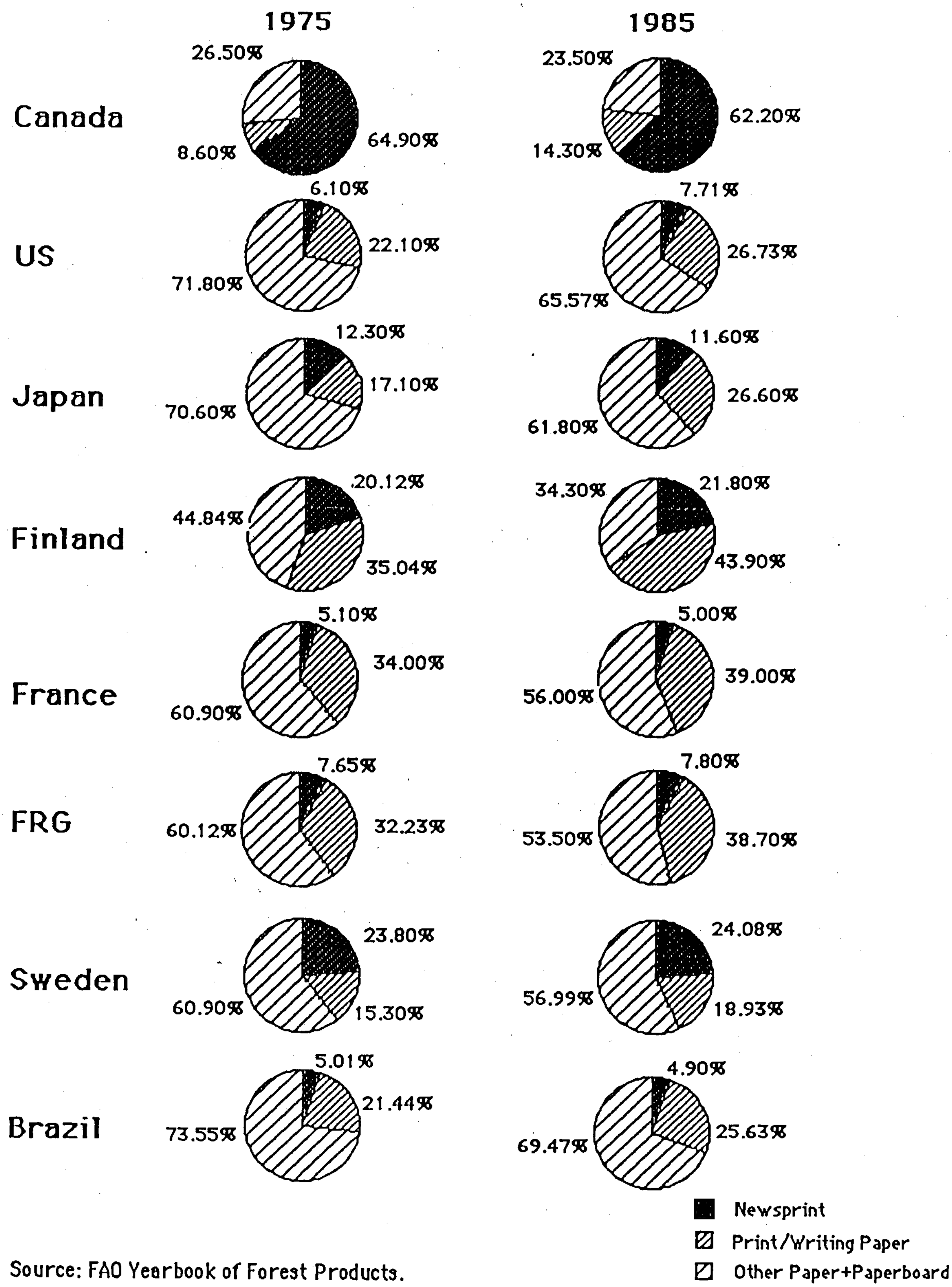
Secondly, pulp and paper firms diversified into higher value-added products. These included such printing and writing paper grades as fine paper, supercalender (SC) grade, lightweight coated (LWC) papers and other office and computer grades (Fig 3.16). While this strategy was adopted by firms in all the major pulp and paper regions it was much more pronounced in the European market than in the North American market. In particular, Swedish firms adopted what has been called *scissor pricing* method. The export prices of pulp grades were raised over and above those of paper grades and allied products. This caused a decline in pulp exports. . The surplus pulp were then diverted to produce high-valued paper. At the same time, paper exports increased by 46 per cent as against 17 per cent from 1971 to 1976. In contrast, Finnish firms shifted the emphasis within the pulping and paper sectors themselves. In the pulp sector, the shift was from low-grade mechanical pulp to high-grade chemical pulp. In the paper sector, it was from newsprint to printing and writing paper and other higher value-added grades. In order to be able to compete the higher quality grades being produced by the Scandinavians, West German firms also moved into higher value-added printing and writing grades. As a result newsprint production was relegated to a secondary position in the German paper industry, until about 1980, while more emphasis was placed on such printing and writing grades as *light weight coated (LWC),* uncoated SC papers and office and computer grades.

Conclusion

The purpose of this chapter was to provide the appropriate industrial perspective for the understanding of the choice of the twin-wire paper machine by pulp and paper firms. From the discussion of the main points relevant to the study of the technology choice in the industry can be noted as follows: First, the pulp and paper industry is not only one of the oldest but also the most capital-intensive industries in the world. As a result of considerable existence of economies of scale, production units in general tend to be large even though some of them may be admittedly small due to specific local conditions. This also means that technologies that further enhance these scale

FIG. 3.16: DIVERSIFICATION IN PAPER PRODUCTION IN SELECTED YEARS

(BY % CAPACITY)



Source: FAO Yearbook of Forest Products.

economies will, in general, receive favourable response from firms. However, the scope of these economies of scale differs from sector to sector, time and even place. The extent of economies of scale in the newsprint sector, for example, is much bigger than in the mechanical pulp sector. The need for a large mechanical pulp mill may therefore have to be compensated for by a bigger paper machine. Demand for some of the technologies is often joint or complementary.

On the demand side, the product market of the industry also shows some variations. In the bulk sector of newsprint and linerboard demand conditions are such that the two products have to be highly standardised. Changes in the standardised quality is dictated by the market. As a result, technologies choices are not made unless market conditions indicate that such actions are safe. This also means that once changing market conditions have generated the new technologies, firms cannot stay on for long without adopting the new technology since they stand to lose if they stay away from the new technology. Thus while firms may be hesitant in making decisions about new technologies, once the process is initiated, and market conditions give continued support to it, the reaction of other firms can be rather swift. In contrast, technology choices can be used as a weapon in the value-added sector.

This also has implication for information flow. In the value-added sector, technologies are more likely to be guided as company 'trade secrets' and by patents while in the bulk sector this cannot be the case. In this case also information barrier may not be an obstacle for the bulk sector operators while it may be for those in the value-added sector. In view of the high capital cost of the industry, it can be asserted that availability of capital and extent of market competition are more likely to influence adoption of technologies than information barrier or firm size.

In general, Canadian pulp and paper firms share in these characteristics. In particular, with its overwhelming strength in low-grade bulk sector, it can be concluded that first, information flow is not a constraint to the adoption of the twin-wire paper machine; second, market pressure and third, potential of achieving economies of scale are more likely to be important reasons for adoption. At the moment these can be considered as speculations which can be fully understood when the technological, spatial and managerial contexts of choice are made.

CHAPTER IV

THE TECHNOLOGICAL CONTEXT

Technology choices made by manufacturing firms primarily involves a comparison between the technology in current use by the firm and a new technology. Firms do not adopt new technologies unless, on the basis of certain criteria, they find it satisfactory to do so. For example, no firm will adopt a new technology unless the technology is compatible with its production and other business objectives. Even compatible technologies may not be adopted unless it can be established that they can yield greater benefits than the current technology being used by the firm. Whatever the case may be, the criteria used to evaluate the decisions are in themselves dynamic and tend to be influenced by the changes taking place in the characteristic of the new technology. For once innovated, technology is constantly refined and modified. Incremental and radical technical changes may occur in the original version which will, in turn, redefine the risk and uncertainity as well as compatibility and profitability elements of the original version. Technologies which were formerly incompatible, risky and not profitable may become compatible, less risky and profitable and vice versa. As new variations of the technology emerge, the range of choice widens and new areas of application become possible. For these reasons, the research and development (R&D) environment within which technology choices are made is important to the understanding of the process of technology choice.

This chapter focusses on the technological context within which pulp and paper firms in Canada made their twin-wire technology choices. In particular, it focusses on the evolution and development of the twin-wire paper machine and its relevance to the twin-wire technology choices by pulp and paper firms. It investigates the following four questions: What was the existing papermaking technology before the twin-wire? What are the main characteristic features of the twin-wire technology and why was it developed? How did the twin-wire develop and what has been the main development patterns? What implications have these developments had on the choice of the twin-wire technology? These questions are examined within the broader background of the technological environment of the pulp and paper industry.

The information which forms the basis of the answers to these questions was obtained from published materials and interviews. Published documents included material on the history of the Fourdrinier and the twin-wire paper machines from such journals as the Pulp And Paper International (PPI), the Pulp And Paper Magazine of Canada, Pulp & Paper Journal, Pulp And Paper, Svenska Papperstinding, Paper, Paper Trade Journal, Technical Association of The Pulp And Paper Industry (TAPPI) Journal , Indian Pulp And Paper Journal, as well as books and proceedings from pulp and paper association conferences. The interviews were conducted with 11 R&D and marketing managers of four twin-wire builders namely, Black Clawson, Beloit, Valmet and Voith, regarding the history and developments in their respective twin-wire versions and why those developments were undertaken. More published and unpublished documentation was obtained from these sources also.

The chapter is divided into five sections. First, the technological capability of the pulp and paper industry, as signified by its research and development (R&D) system, is reviewed to provide a general background for the twin-wire study. Second, the paper machine technology before the emergence of the twin-wire paper machine is briefly examined. Third, the concept and characteristics of the twin-wire paper machine are explained. Fourth, the reasons for the development of the twin-wire are outlined. Fifth, the evolution and major development patterns of the twin-wire concept and the reasons behind those patterns are examined. Finally, the relevance of these developments for the choice and for that matter diffusion of the twin-wire technology are discussed.

The R&D System of The Pulp And Paper Industry

The R&D system of the global pulp and paper industry, as in all manufacturing industries, can be classified into two main groups, specifically the *Public Sector R&D System* and the *Private Sector R&D System.* The public sector R&D system consists of wholly or almost government-supported institutions and structures that do research and development work related to the pulp and paper industry. Broadly, they consist of two main groups: Universities , Technological Institutes and Government Central Research Institutes, Laboratories (Government and University R&D). In the Centrally Planned Economies, the whole R&D System of the industry consists in this type since all institutions and structures are state-owned.

In contrast, the private sector R&D system consists of institutions which are completely supported by the private sector and may receive very little support from the government. In the pulp and paper industry these fall into three sub-systems. The first is in-house R&D activities of the pulp and paper firms or what may be termed *industry R&D.* The second is *co-operative R&D*, which consists of R&D activities that are supported by co-operative efforts of pulp and paper firms within a given country or region and the third is *supplier R&D*, which consists of R&D activities of firms in the machinery and chemical industries which produce process equipment and chemicals used by the pulp and paper industry. In addition to the two broad classifications of public and private, a third class of R&D system consisting of joint public and private sector agencies can be identified.

All three systems perform three main kinds of research, namely *basic* , *applied* and *development.* The first is defined as "the search for fundamental laws and is the study of natural and social phenomena for its own sake" while the second is usually considered as application of the "results of basic research to a specific process, material or device on an industrial scale, to meet commercial objective" (Hayter, 1988). In addition, two other types of R&D work are usually identified in the industry. The first is the fast solution of individual daily problems that require immediate answers Allan (1979) has referred to as *troubleshooting* and the second is the development of products, machines, systems, testing, measuring and controlling as well as bringing the new process or product to the production or market stage.

Public R&D System

Generally speaking, the first formal organised research and development activities leading to the supply of technologies in the manufacturing sector can be directly or indirectly traced to the public sector R&D system. By their charge to teach and research , universities and other educational institutions were the first to turn out trained scientists and other professionals who subsequently became research staff in the private R&D systems in the manufacturing sector. In some cases research faculty have even spearheaded major technological developments. The pulp and paper industry has had its fair share of benefit from this general role of the public sector R&D system. The early research activities however, were undertaken by researchers which were not directly linked to the industry but whose areas of interests were of relevance to pulp and paper technology.

At the turn of the 1900s, this situation began to change when some national governments and other public institutions established specific schools for the industry. The first of these, the Institute of Paper Technology, Darmstadt, Germany opened in 1905. In 1908 another institute, the Institute of Cellulose Chemistry also at Darmstadt opened. In the same year, the Helsinki University of Technology was also opened by the Finnish government. In 1913, the University of Maine established its School of Papermaking as the first of its kind in North America. Other universities in papermaking regions of North America later set up similar schools. Among these were the New York State College of Forestry at Syracuse, Western Michigan University at Kalamazoo, North Carolina State University at Raleigh, Miami University at Oxford, Ohio, University of Washington at Seatle, Unversity of British Columbia at Vancouver and McGill University at Montreal (PPI 1959; Macdonald, 1972). By 1950, all the major pulp and paper producing regions had a network of institutions which were primarily concerned with training technical and professional staff and conducting basic research for the industry. In addition to this role, faculty members maintained strong links with the industry and sometimes undertook contract research for the industry. During the 1950s and 1960s when industry R&D began to boom, not only did the graduates of these institutes become the research and development staff but some of the faculty also held the first R&D director appointments in the industry (Allan, 1979).

Co-operative R&D

While public sector R&D system was initiated largely by governments and educational institutions, co-operative R&D can be considered as the first organised efforts by the industry itself to appropriate the benefits of R&D to its operations. The initiative for the establishment of these R&D facilities came from the national associations of the pulp and paper industry. Among the first of these associations were the German Paper Mills Association, which was founded in 1872, the Finnish Wood Pulp Union of 1892, the Swedish Paper Mills Association of 1898, the Canadian Pulp And Paper Association of 1913 and the American Pulp And Paper Association. Special associations, Technical Association of the Pulp And Paper Industry (TAPPI) were also formed in the Scandinavia and North America and later in Britain, Australia and Japan, to promote the application of technical knowledge to the industry.

As a result of the presentations made with their respective countries, government collaboration was obtained for the establishment of the R&D institutions fully devoted to research and development into the needs of the pulp and paper industry and fully supported by pulp and paper firms. The first of these institutions was the Finnish Pulp And Paper Research Institute (FPPRI), Tapiola, which was established in 1916. This was followed by the Pulp And Paper Research Institute of Canada, (PAPRICAN), Pointe Claire, in 1925 and the Institute of Paper Chemistry (IPC), Appleton, US in 1929. In 1936 the Swedish Pulp And Paper Research Institute (STFI), Stockholm, was established (Macdonald, 1972). Around this period, the All Union State Research Centre for the Pulp And Paper Industry opened in Leningrad (Wilson, 1966). In 1948, the Centre

Technique de l'Industrie de Papieres, cartons et Cellulose (CTP), Greenoble, France, opened (Haas, 1971). These were later to be joined by Japan Pulp And Paper Research Institute and others in Australia, India and Brazil.

As co-operative institutes, these centres provided the advantage for pulp and paper firms to support jointly research projects which could not be supported by individual firms either because of lack of funds, staff, facilities, because returns to R&D could not be privately appropriated or because of the high risk nature of the project. Firms which could not benefit from R&D activities had the opportunity to benefit. The centres engage mainly in applied research and some basic research and development work. The research agenda are drawn by the Institute and the representatives of supporting firms and as such are highly determined by the needs of the industry. Thus since 1950s, these institutes have mainly engaged in such areas as energy and environmental problems, new chemical pulping processes, new product development such as wood-containing printing and writing papers, improved paper quality for printability, new bleaching processes, some of which have led to new technological innovations. These institutes also undertake contract research for specific member firms. They also collaborate with established machinery firms when they want to commercialise an invention. In addition to their research activities, the institutes also undertake graduate training of students who go out to take various research positions in the industry. Prior to the 1950s these institutes constituted the only R&D services to most pulp and paper firms in the industry because only few firms had their own R&D facilities. However, as individual firms began to establish their R&D facilities, this function began to diminish in certain regions and in Sweden for example the STFI now undertakes only about 15 percent of the pulp and paper R&D activities (Stockman, 1986).

Industry R&D

Although technical and process engineering departments in pulp and paper firms have long been involved with "troubleshooting" type of work, some of which had led to important development work, in comparison with the public sector and co-operative R&D, formal in-house R&D may be considered as a recent development. As already pointed out, in 1950 only a few firms industry had in-house R&D facilities. Among these were Wiggins Teape (Hendry, 1986) and the Howard Smith Research Laboratory in Canada who had established their facilities in 1920s (Allan, 1979; Hayter, 1988). In the US, it included the Rayonier Company, Scott Paper, Kimberly-Clark and Crown Zellerbach (OEEC, 1951). During the 1950s and 1960s, however, a number of pulp and paper firms established research facilities. In Canada for example, Allan (1979) indicates that by the end of the 1950s, there were about 7 in-house R&D facilities and by 1968, the number had increased to 15 with a staff of about 1000.

In general, the research work done by these centres produced very important results most of which later on led to important technological developments. Among these, in Canada for example, were the Arbiso high yield soda pulping, the centrifugal cleaner, the Vortrap and the Vorject cleaners, the magnefite pulping process, the Arbiso sodium base pulping process, and pollution abatement technologies.

However, since the second half of the 1970s, in-house R&D activities seem to have lost momentum particularly in North America (Pulp & Paper Journal, 1987; Hayter, 1982, 1988, Allan, 1979). In Canada, in particular, a number of pulp and paper firms began to question the essence of keeping large R&D staff when the energy crisis and environmental concerns raised their production and maintenance cost. As a result in-house R&D centres became targets in the "structural rationalisation" programme. The research centres of Abitibi, and Consolidated-Bathurst were both reduced by half, and MacMillan Bloedel by a third. Canadian International Paper (CIP) closed down its Gatineau Research Division and cut down on staff. Domtar also cut down on staff.

Columbia Cellulose went bankrupt and the research lab was sold later to Econotech, a consulting company. As the research centres closed down, so also were the number of professional staff reduced. The result was that by the mid-1980s many pulp and paper mills had reduced their R&D staff so much so that their activities had been reduced to the "troubleshooting" type of work. The companies therefore had to resort to using engineering consultants for work that was formerly done by established R&D departments.

In addition, the difficulty in balancing the books obviously led to a cut-back in R&D funding, which dropped from over 0.8 per cent of sales around 1968 to less than 0.35 per cent by 1979 (Allan, 1979). Three years later Hayter (1982) observed that one US forest product company, Weyerhauser, alone spent more on R&D in a year than all Canadian forest companies combined. By 1987, this situation had not changed. While the amount spent on R&D had risen by 0.1 per cent of sales over the 1979 amount, this was still about one-third to one-half the amount spent by the US and Scandinavian firms (Pulp & Paper Journal, 1987). In the US similar observation concerning the limited in-house R&D activities and increasing reliance on contract research organisations for research and development were also made by Jacomet (1984). In spite of this decline in Canada and to some extent in the US, in-house R&D has been an important source of new ideas which have led to important innovations particularly in process technologies and still continue to be important especially in other pulp and paper regions like the Scandinavia.

Supplier R&D

The technology of the pulp and paper industry is capital-intensive. The development cost of such technologies is so large that it can only be recovered by selling the products to many customers. This type of R&D is just not suitable for a paper producer (OECD, 1988). As a result the pulp and paper industry is served by a large diversified supplier industry, which undertake its own R&D activities to develop new machinery equipment and other products which then become new technological developments for the pulp and paper industry.

This type of R&D includes those carried out by paper machine builders, producers of paper machine fabrics, producers of chemicals required by the industry, producers of microelectronic products, electric motors, and computers required by the paper machine builders, and producers of pulping machines such as refiners and digesters. Most of the recent developments that have taken place in the paper making sector and the pulping sector related to machinery have all been due to this supplier R&D. Apart from being directly responsible for the development of the hardware technologies, an important factor that has also affected the supply of pulp and paper technology since the 1950 is the competition among the suppliers. An example of this is the twin-wire paper machine in which competition among major suppliers resulted in proliferation and increased development of different versions of the machine.

Information Pathways

The invention of new technologies does not necessary lead to technological change in an industrial setting. The invention must be exploited and become commercially acceptable by the industry before it can constitute technological change. Since inventions usually originate in a few R&D centres, a crucial factor in getting the general acceptance of the industry is information flow (Hagerstrand, 1953). All R&D systems have a network of information pathways which perform this function, a network which Hayter (1988) has called *technological liaisons*. In this case, one of the important roles of technological liaisons in the supply of technology is to reveal what technology is available and what is going to be available in future. The speed with which technological liaisons can perform this important function usually depend upon the "openness" of their pathways which in turn depend upon the type of R&D system which developed the new technology.

It is reasonable to expect that inventions generated from within the industry, that is from Company R&D systems, would not diffuse easily as those generated outside the industry. In the pulp and paper industry the overwhelming role of supplier and co-operative R&D in developing technological innovations, and of trade and technical associations and the nature of the product market, particularly for the bulk sector all combine to leave the information pathways fairly open. First, as we have already pointed out, it is imperative for supplier firms to contact and sell their products to as many pulp and paper firms as possible. Regular contacts are therefore maintained with all pulp and paper firms about latest developments, even though each supplier may have its own "traditional" customer. Second, co-operative institutions are obligated to disseminate the findings of their co-operative R&D activities, which constitute the bulk of their R&D activities. Third, national and international industry associations usually hold annual meetings which among other things do focus on problems in specific areas of the industry such as chemical pulping, mechanical pulping, bleaching, wet end and coating. These special technical sections provide important forum for researchers inside and outside the industry from around the world to readily share their findings regarding the latest technological developments in the industry. In Europe, international co-operation among the Scandinavian countries regarding technological developments have long existed resulting in joint ownership with such supplier firms as Kamyr. In recent years EEC members have established a joint research group which broadly determines the research needs of the EEC paper industry and delegate research projects to member countries. The findings are then disseminated to firms in the industry. Other bilateral exchange of ideas on technological developments do exist among certain leading countries. An example of this is the Swedish Mission to North America which has been in operation since 1950. Delegates from national associations and individual firms also trottle the globe every year to familiarise themselves with latest developments. Fourth, customers of the bulk paper sector such as large newspapers must have several suppliers to provide for greater security of supply. Irrespective of source they require that each roll of paper must be identical to permit uniform printability. Information about quality therefore adisseminates very fast thereby leading to standardisation of equipment required for that sector. Finally, over a dozen pulp and paper trade journals exist which publish a great deal information about latest developments in the industry.

Given this network of information pathways, the "lead time" for even those who innovate from their own in-house R&D is short since it does not take long for a new technology to diffuse once it has been accepted. For the same reason too it is possible for firms or regions with low technological capabilities to compare equally well with strong technological capability firms or countries in the use of the most modern technologies in the industry. However, this will also depend upon the specific type of R&D system which initiated and further developed the technology.

The Paper-Making Machines Before The Twin-Wire

The Fourdrinier Machine

Before the emergence of the twin-wire former in the late 1960s, there were two main types of paper-making machine- the *Fourdrinier* and the *Cylinder* paper machines. The Fourdrinier machine, was invented in 1799 in France by Louis Robert. Robert later sold his interest in the patent to Leger Didot who, on the advice of John Gamble, moved over to England in 1800. Employing the service of Bryan Donkin, Didot greatly improved the Robert machine and a British patent was granted Gamble. In 1803, a paper web was first formed on a continuous basis on the machine. In 1804 paper merchants, Henry and Sealy Fourdrinier, purchased the remaining interest of Didot and Gamble and, on the advice of Donkin, made further changes in the machine. In 1807, Gamble assigned all his rights in the patent to Henry Fourdrinier, and the initial patent was extended to incorporate the new changes that had been made. In 1810, the Fourdrinier brothers went bankrupt having spent about £60,000 on the development of the long flat web-forming section, which later came to be called the Fourdrinier wire (Nutter, 1970).

However, with the help of new inventions such as Crompton's steam cylinders of 1823 and Marshall's dandy roll of 1826, by 1889 and 1890, the Fourdrinier machine, as the entire machine came to be called, had reached such a perfection that at the time the twin-wire machine came into the scene in the 1950s and 1960s the Fourdrinier was still characterised by the essential feature of an endless wire mesh belt supported, by a series of rolls and other control devices in a horizontal position (Holt, 1964). Together with its auxiliaries, the main components included, even as it is today, a *flowspreader* for spreading the flow of stock from a delivery pipe into the width of the machine; a *headbox* to improve the uniformity of the stock flow; a *Fourdrinier table* section which had the hardware necessary to support the *Fourdrinier wire* on which the sheet is formed; a *press* section to receive the wet mat of sheet for further dewatering; a *dryer* section consisting of heated cylinders for drying the sheet; a *calender* section for smoothening the surface of the dried sheet and a *reel* for winding the dried sheets into large rolls of paper (Holt, 1964). The section including the headbox and the Fourdrinier table is usually called the *wet-end* or *forming section* while the remaining parts constitute the *dry-end* or *drying section*

The Cylinder Paper Machine

Like the Fourdrinier machine, the Cylinder machine was developed about 1800 in both the United Kingdom and the United States. In 1807, the first patent was granted in the United States to Charles Kinsey and in 1809 a British patent was granted to John Dickinson. Since no further mention is made about the Kinsey machine from this point, it is generally accepted that the machine was a non-starter. However, Dickinson's machine survived and in 1820, George Shryock in the United States innovated the manufacture of paperboard on a Cylinder machine. In 1830, a Cylinder machine equipped with a press, steam-heated dryers, reel and sheet cutter, was built by Phelps and Spafford of South Windham, Connecticut, and in 1870, Shryock again innovated paperboard manufacture on a multi-cylinder machine.

The essential difference between the Cylinder machine and the Fourdrinier machine is that the forming section of the Cylinder machine is characterised by a cylinder mold surface covered with fine wire cloth, which revolves in a vat of paper stock. The number of cylinders will depend upon the type of product. Cylinder machines used for the production of thin papers such as tissue have only one cylinder and are referred to as *single-ply* machines while those used in the manufacture of paperboard have several cylinders and are also referred as *multi-ply* machines. A multi-ply machine used in the production of very thick paperboard may have as many as nine cylinders, with each cylinder producing a layer of board which are later on pressed together. Cylinder machines are also classified into *direct-flow* and *indirect-flow*. A direct-flow Cylinder machine is the one in which the vat feed is in the same direction of the cylinder rotation, while an indirect-flow Cylinder machine is the other way round (Nutter, 1970). Apart from the cylinders, the rest of the Cylinder paper machine are the same as the Fourdrinier. However, the inherent design and operating characteristics of the two machines combined with the process technologies involved in producing the different paper grades made the Cylinder machine capable of producing a wide range of paper grades, particularly with reference to paperboard and some tissue grades, while the Fourdrinier became more capable in producing paper grades other than paperboard.

Characteristics And Classification of Twin-Wires

Principle And Meaning of Twin-Wire Forming

Twin-wire forming implies the dewatering of pulp suspension between two wires. The dewatering process, which is achieved by the use of increased pressure between the two wires, may be two-sided, that is through both wires, or one-sided. The latter occurs in the production of tissue and paperboard. In two-sided dewatering one sheet is formed on the inside of each wire and subsequently couched together. Generally, a twin-wire paper machine may therefore be described as a paper machine with two wires that allows two-way dewatering process during the sheet-forming process.

Pure Twin-Wires or Gap Formers

Twin-wires are generally classified into two main groups- *pure twin-wires or gap formers* and *hybrid* or *preformers* or *top formers*. Gap formers are characterised by injection of a free jet between two wires, while top wire formers have a Fourdrinier preforming section followed by a top wire former for drainage (Sinkey and Wahren, 1985, 1986; Stowe, 1985).

Gap formers may be designed as new machines or rebuilds of old paper machines. According to the element used to define the forming section, gap formers can be further classified into *roll formers* and *blade formers*. In roll formers, with two-sided dewatering, the two wires wrap a solid or open forming roll and in contrast to the Fourdrinier, removal of water occurs without any pulsation. Instead it dewaters due to vacuum, through the bottom wire, and due to centrifugal force, through the outer wire around the forming role (Stowe, 1985; Sims, 1985). Subsequent drainage may either be by vacuum or by centrifugal force depending upon the configuration of the machine. Without any stationary elements, roll formers usually require less power, but as a result, no additional energy is imported to the sheet to break up flocs. The jet is rapidly set in position which therefore requires a headbox that can provide excellent fibre dispersion if good formation is to be obtained. [1] In general, in most roll formers, especially open roll formers, the dewatering process is two-sided. However a few roll formers, particularly those designed for tissue production have one-sided dewatering system. In this type of roll former, drainage is due to centrifugal force action around the forming roll.

In contrast to roll formers, *blade formers* have a stationary forming zone. The wires move over blades which create pressure pulses causing shear and turbulence in the forming zone. These aid drainage and also add energy to the sheet to break up flocs and thus rearrange the fibres during the sheet-forming process to improve formation. (Stowe, 1985; Sinkey and Wahren, 1985, 1986; Harwood, 1987).

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1. Formation is the degree of uniformity of the fibre distribution in a sheet of paper (Smook, 1982) and is usually the sheet property one observes when the paper is held against a transmitted light (Straus, 1964). A uniform distribution is described as "close formation" while an irregular distribution is described as "wild formation".

Hybrid or Top-Wire Formers

Like gap formers, *hybrid* formers may also be designed as new machines or rebuilds of old paper machines. Whether designed as new machines or rebuilds of old machines, hybrid formers usually have a section similar to the Fourdrinier forming section, followed by a top wire. Apart from these forms, hybrid formers may also be designed as retrofits to existing Fourdrinier machines. In this case the design consists in only a *top wire* which can be retrofitted on to a Fourdrinier machine after some adjustments have been made on the latter. Like gap formers, hybrid formers may employ roll forming and or blade forming principles to remove water through the top wire. In *hybrid blade formers*, initial dewatering takes place on the normal Fourdrinier table while dewatering through the top wire takes place over a curved shoe. The direction of the shoe could be upward or downward depending on the machine builder. Whichever way, the device induces energy during the forming process causing dewatering either by vacuum or by centrifugal force. *Hybrid roll formers* operate on the same principle as the pure twin-wire roll formers except that they do have a Fourdrinier preforming section. A few hybrid formers operate as a combination of both roll and blade or stationary principles (Stowe, 1985; Sinkey and Wahren, 1985; Harwood, 1987)

Since hybrid formers have top wires in addition to Fourdrinier preforming sections, they are able to control some of the inherent shortcomings of the Fourdrinier and at the same time gain the advantages of two-sided dewatering (Sinkey and Wahren, 1986). The different types of existing pure twin-wire and top wire machines, as of 1988, are given in Table 4.1.

Reasons For The Development of The Twin-Wire Paper Machine

The main reason for the development of the twin-wire paper machine was the inability of the then existing paper machines, namely the Fourdrinier and the Cylinder paper machines, to meet the changing needs of the paper world. In the case of the Cylinder machine, even though it could

Table 4.1: **Existing Twin-Wire Paper Machines As of 1988**

Class	Type of Unit		Manufacturer
Pure Twin-Wires	Roll Formers		
	One-sided dewatering	Beloit Tissue	Beloit Corp, US
		Duoformer T	J. M Voith, FRG
		Periformer LW	KMW, Sweden
		Tisco Former	Escher-Wyss, FRG
	Two-sided dewatering	Duoformer C, E	J.M Voith, FRG
		ErWePa Former	ErWePa, FRG
		Over Former	Over-Meccanica
		Papriformer	Dominion Eng., Canada / KMW, Sweden
		Periformer MW	KMW, Sweden
		Speed-Former T, Speed-Former HS	Valmet, Finland
	Blade Formers	Bel Baie I, II, III	Beloit Corp, US
		Verti-Forma I, J, V	Black Clawson US
Top Wires	Rolls	Bel-Roll	Beloit Corp, US
		Dynaformer	Dominion Eng. Canada
		Duoformer F, H, K, L, D	J.M Voith, FRG
		Periformer MW, LW, HR	KMW, Sweden
		Twinformer L	Escher-Wyss, FRG
	Stationary	Bel Bond, H. Bel Baie	Beloit Corp, US
		Akumat	A. Kufferath
	Rolls & Stationary	Bel Form	Beloit Corp, US
		Sym-Former F, N, SF, R	Valmet, Finland.
		Speed-Former HHS	Valmet, Finland.
		Top Flyte	Black Clawson, US
		Alform M	Ahlstrom, Sweden ?

H. Bel Baie = Horizontal Bel Baie.
Source: Sinkey and Wahren, 1985 and Author's Survey.

produce a much greater variety of paper than the Fourdrinier, at the early stages of its development it was found to be severely hampered by centrifugal force as operating speed increased. In addition, there was a "wash-off" effect on the deposited fibre as they dragged through the fibre suspension vat (Castagne, 1965).

The Fourdrinier also had a number of problems that related to paper quality and machine speed. First, the Fourdrinier paper was two-sided. The one-sided dewatering process on the Fourdrinier wire during the sheet-forming process created a tendency for long fibers in the furnish to settle on the wire while the fines[2] were either thrown out or left to settle on the web formed by the long fibers. The result was a non-uniform distribution of fibre length, fines and fillers through the thickness of the sheet leaving a smooth wire-side surface and an undulating top surface. As the speed of pressroom machines increased and more tabloid and coloured advertisement, which required much stickier ink, were introduced it became clear that the Fourdrinier paper, particularly newsprint, would need quality improvement in order to meet the new demands. In particular, there was the need for a sheet of paper that would print equally well on both sides. Many pulp and paper companies, particularly newsprint producers, tried to improve the quality of the Fourdrinier paper by spraying starch on the Fourdrinier wire during the forming process so as to make the fines stick together. However, this was without much success.

The second problem was that the Fourdrinier paper had a poor formation. Even though good formation depends a great deal on the part of the paper machine called the headbox, and even though advances in headbox technology had greatly increased the capability of headboxes in delivering stock uniformly on to the Fourdrinier wire, the good effect of those changes was largely lost on the wire because the Fourdrinier machine was not fast enough to prevent flocs from re-forming during the sheet-forming process (Howard, 1973). It was therefore difficult to produce a paper with a fine micro-structure as desired by printers.

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2. The very small fibers and fiber fragments in the furnish that readily pass through a filter wire cloth.

The third problem was that of basis weight, which is the weight per unit area of the paper. Ideally the basis weight has to be uniform. However, it happens that during the forming process, stock issuing on to the Fourdrinier wire has to be in a state of turbulence. The scale of this turbulence though, initially minor, later on increases considerably as the turbulence merge into bigger waves. The result is a random distribution of basis weight in the paper (Howard, 1973).

Fourth, the Fourdrinier machine was not fast enough to meet the needs of the industry. Increasing demand for paper products and increasing need to achieve high level efficiency made high speed paper machines very desirable. However at the speed of 2,500 feet per minute (fpm), the vacuum created by the action of the table rolls, supporting the Fourdrinier wire, roughly matches the vapour pressure of water and as the speed exceeds this point drainage ceases. The result is that although the Fourdrinier could theoretically attain a running speed greater than 2,500 fpm, practically this was unattainable. Besides since paper is formed by taking water out of pulp suspension, if the speed were to go up, then the drainage capacity too had to increase. As far as the Fourdrinier was concerned, the only way this could be achieved was to lengthen the forming zone, which already was about 153 feet long. It was a search for solutions to these problems that led to the development of the twin-wire paper machine.

Evolution And Development of The Twin-Wire Concept

Inspite of the large number of publications on the twin-wire technology a chronological account of the evolution and development of the technology is still a difficult task. This is because the majority of existing works do not deal with the R&D stages of the technology in any detail as they do on installation dates, start-up procedures and results of machine performance after start-ups. Even where they do, as in the works of Norman (1979), Thorp (1982, 1985) and Attwood (1988), details regarding the dates on which the major stages in the R&D life cycle were undertaken are not provided. This is mainly due to the fact that majority of these publications form an essential component of the marketing strategies of suppliers and therefore have certain marketing objectives. It is also due to the inherent difficulty in trying to impose an order on the complex process of the development cycle of a given technology. In the particular case of the twin-wire, this problem is further complicated by a number of parallel and simultaneous developments by individuals and firms, which makes the creditation of who developed what first, difficult to substantiate. In this case patent information seems to be the best, yet even with patent information there is the question of which date to use: whether to use the date on which the concept occurred, the date the patent was applied for, approved or the date a true commercial model was made. In spite of these difficulties, an attempt is made in the following section to present a chronology of the major developments in the twin-wire technology , using information from some of the published sources and also from personal interviews held with suppliers and users of the twin-wire machine.

Early Twin-Wire Developments

Even though the evolution of the twin-wire idea is believed to have started around the 1940s (Norman, 1979) and the 1950s (Attwood, 1988), it is now known that the idea of forming a sheet of paper by dewatering through two wires dates much earlier than these dates. According to Attwood (1979), the first twin-wire was developed in 1813 and many Donkin machines [3] were fitted with 'top wire' units. In the late 1860s J.F Jones is believed to have designed a machine with similar arrangements to those that had been tried in the early part of the 19th century (Attwood 1979, 1988). Verseput (1972) even claims that Louis Robert's original paper machine had two wires. Probably because machinery-making skill at that time was not sufficient enough to make these designs work, the idea was quickly dropped and none of these and other earlier attempts ever saw commercial application. However, about the 1940s the twin-wire idea received some impetus again when some mills in Europe produced paperboard by arranging a number of separate Fourdrinier

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3. The Donkin machines were the improved version of the Robert's machine, due to Bryan Donkin.

forming sections by each other so that individual webs could be combined while still wet. These experiments generated a host of further research and development work first in paperboard-making and the Cylinder machine and later on in the making of other paper grades and the Fourdrinier. Out of research on the Cylinder machine came such developments as the *Suction cylinder, the Semi-Rotoformer, the Rotoformer, the Dry Vat, the Ultra-former,* and out of research on the Fourdrinier came the modern-day twin-wires.

The Development of Modern Twin-Wire Machines

The development of modern twin-wires can be classified into three periods. The first is a *Pure Twin-Wire Era* stretching from 1950 to about 1969 during which emphasis was placed on the conceptualisation and development of distinctive characteristics of different versions of what may be called the first generation modern twin-wires by the paper machine-building industry, dominated concurrently by Europe and North America. The second is the period from 1970 to 1980, during which the continued search for twin-wire versions to meet the needs of particularly the European sector of the industry led to a new wave of twin-wire machines, namely the *Hybrid formers*. Rather distinctive in their design and configuration, this new breed of formers came to present a significant departure from the general trend of twin-wire development. With the first generation pure twin-wire and the hybrid (together with its subsequent top-wire) formers in place the development of modern twin-wires entered its third phase from the 1980s, the *Consolidation Period* in which emphasis on incremental technical changes and various supplier strategy has led to proliferation of the twin-wire paper machine. A summary of selected stages in the R&D processes of the twin-wire over these periods is given in Table 4.2 and the details of the major developments are examined in the sections below.

Table 4.2:**Research And Development History of Twin-Wire Paper Machines**

Manufacturer	Name of Former	Conception Date	R&D Period	Date & Place of Innovation
Beloit	Bel Baie			1969, Quebec North Shores, Baie Comeau, Canada.
	Bel Baie II	1969	1970-72	1972, Jujo, Ishinomaki, Japan.
	Beloit Tissue	1970	1972-76	1976, Edet Nederland, Tilbury, Netherlands.
	Bel Baie III	1975	1982-84	1984, SCA, Ortviken , Sweden.
	Bel Bond	1971	1971-	†
	Bel Roll	?	?	1983, Bowater Southern, Calhoun, US.
	Bel Form	1983	1983-84	1984, Abitibi-Price, Ft. William, Canada.
	Hor. Bel Baie III	1981	1984-87	1987, BCFP, Crofton, Canada.
Black Clawson	Verti-Forma I	1956?	1957-63	1968, CIP Inc., Trois-Rivieres, Canada.
	Verti-Forma J	?	?	1969, Daishowa, Yoshinaga, Japan.
	Top Flyte 'S'	1982	1982	1983, Abitibi-Price, Pine Falls, Canada.
	Top Flyte 'C'	1986	1986-	1988, Abitibi-Price, Thunder Bay, Canada.
Dominion Engineering	Papriformer	1950s?	1959-1965	1972, Kruger Inc., Bromptonville, Canada.
	Dynaformer	1976	1976-81	1981, Fukuyama, Japan.
KMW	Periformer LW	1950s	1960s?	1975, Fiskeby, Katrinefors, Sweden.
	Periformer MW			
Valmet	Sym Former F	1970	1970-73	1973, United Paper Mills, Simpele, Finland.
	Sym Former N	1971	1973-75	1977, Oy Ahlstrom, Varkaus, Finland.
	Sym Former SF	1979	1979-80	1981, Metsa-Serla, Kirkniemi, Finland.
	Sym Former	1980	1980-84	1982, MoDo, Husum, Sweden.

Contiunued on the next page

Table 4.2: **Research And Development History of Twin-Wire Paper Machines** *(Conclusion)*

Manufacturer	Name of Former	Conception Date	R&D Period	Date & Place of Innovation
Valmet	Speed Former	1975	1976-78	1978, A/S Union, Skien, Norway.
	Speed Former HS	1985	1985-87	1987, A/S Union, Skien, Norway.
	Speed Former HHS	1985	1985-87	1989, James River, Wauna, US.
Voith	Duoformer E		1972	1974, Daishowa, Iwanuma, Japan
	Duoformer C		1975	1977, Holmens Bruk, Braviken, Sweden
	Duoformer T		-	1978, Marcal Paper, Elmwood Park, US
	Duoformer F		1976	1978, Prommashimport, Kamsk, USSR
	Duoformer H		1981	1982, Haindl Paper, Achongau, FRG
	Duoformer FM		1986	1987, Jujo Paper, Fushiki, Japan
	Duoformer HM		1986	
	Duoformer D		-	1985, Kappa Scolten, The Netherlands
	Duoformer K			1978, Rando Ganahl, Feldkirch Frastene, Austria
	Duoformer CF		1987	1989, Finlay Industries, Mackenzie, Canada.
Escher Wyss	TwinFormer			
OverMeccanica	OverFormer			
ErWePa	ErWePa			

† According to John Harwood, Manager of Paper Machine R&D at Beloit, several inverform units were rebuilt to Bel Bonds . The first started up in 1973 at Australian Paper Manufacturers, Fairfield, Australia. However, Beloit's efforts began in 1978 and the first Bel Bond to start up on paper grades was at MacMillan Bloedel, Powell River, B.C in 1980.
The dates for the Voith machines were the dates the machines became available for sale.

Source: Author's Survey.

The Pure Twin-Wire Era

David Webster's Roll Former

Available evidence from the work of Norman (1979), Attwood (1979) and Thorp (1985) indicate that the invention of the modern twin-wire former should be credited to David Webster of Consolidated Paper of Canada (now Consolidated-Bathurst Inc), who as early as 1953 had developed a working model of a roll-former, in which stock was injected between two wires. According to Norman (1979), Webster had conducted private experiments by entering pulp suspension between a rotating roll and a wire wrapping the roll, in order to achieve two-sided dewatering. In 1953, Webster applied for a patent for his invention from both Canada and the United States. However, his application was neither granted in Canada nor in the US until 1961 and 1962 respectively, after he had refiled it in 1959.

During the decade in which Webster had to wait for his patent, a rapid development of similar ideas occurred among research institutes, paper machine builders and paper consuming companies such that by the early part of the 1960s a number of what may be called the 'first generation' twin-wires had been developed and commercialised, patented or were at the experimental stage. Among these were the *Inverform*, by the St. Anne's Board Mill of the UK, the *Verti-Forma* by Black Clawson, the *Papriformer* by the Pulp And Paper Research Institute of Canada (PAPRICAN), the *Bel Baie* machine by Beloit Corporation of the US, and the *Periformer* by Karlstad Mekaniska Werkstads (KMW) of Sweden.

The Development of The Inverform

The development of the Inverform was due to Brian Attwood and his associates at the St. Anne's Board Mill, Bristol, UK when a decision was made at the mill in 1950 to develop a method of producing high quality folding boxboards at speeds in excess of those of the Cylinder mould machines. A pilot plant was set up at the mill in 1951 and a number of experiments were made by locating a number of headboxes and a wire on top of a Fourdrinier paper machine. The two wires allowed dewatering on both sides of the sandwiched stock resulting in a considerable improvement in the two-sidedness of the Fourdrinier paper. Between 1952 and 1954 more trials were conducted and in 1955, it was decided that the No. 4 machine at the mill be converted to an Inverform unit. Two years later the machine started its first commercial operation and thus became the world's first commercial twin-wire (Attwood, 1960; 1979). Two paper machine builders, Walmsley and Beloit, were given licensed rights to produce the machine: the former for Europe, Africa, Australia and Asia except Japan, the latter for North America, Central America, South America and Japan. By 1968, many Inverform and its derived versions such as the *Twinverform* were producing paperboard in several parts of the world.

The Inverform was indeed the world's first commercial twin-wire. However, since it was developed for producing only board grades, its impact as a technological breakthrough in paper-making was accordingly limited to that sector. It was not until the twin-wire concept was applied to the production of other grades, where solutions to the problems of the Fourdrinier machine were of great significance to the survival of the paper industry, that the twin-wire machine claimed the credit as the most significant technological development in the history of paper-making since the invention of the Fourdrinier. Even so, the Inverform merits the epitaph assigned to it by Thorp (1985) as the *grand-daddy* of modern twin-wires and it is from it that the first generation twin-wires developed.

The Development of The Verti-Forma

The *Verti-Forma* was the first twin-wire machine to gain world-wide acceptance for the production of paper grades, other than paperboard, and particularly for newsprint (Norman, 1979). The story of the machine's development began in 1956 when Joe Baxter, the research director of the Black Clawson Company, Watertown, US, saw an advert in the October issue of the Paper Trade Journal by Time Life Magazine, Springdale, New York asking for mechanical engineers to sign up for the development of a new type of paper machine capable of producing a uniform quality magazine paper. About three months later, Baxter went on a duty call to one of his Company's customers in Springdale and took the opportunity to see Time-Life Magazine to find out more about what they had in mind. There he met Paul Thoma, who explained to him that he wanted a machine that would produce a sheet with identical surfaces in order to reduce coating required and also weight which would mean $10 million postage cost saving for Time Life magazine every year. Thoma explained further that all the tests they had performed to obtain such a sheet on the Fourdrinier had not been successful so Time-Life was prepared to reward anyone who, would design a machine to produce the kind of paper they wanted, to the amount of $60 million (Black Clawson, 1968).

Between December 1956 to February 1957, Baxter developed his ideas. First, he recognised that the only reason why the Fourdrinier paper was two-sided was because of the one-sided dewatering process. Baxter made a sketch of the Fourdrinier and put a separate wire on top so that half of the water could be drained through the bottom wire and the other half through the top wire. Second, he recognised that if water could be removed through both the top and the bottom wires, then the Fourdrinier section of the paper machine could be shortened. Third, he realised that if the two wires were to stay in a horizontal position, gravity was going to work in favour of the bottom wire and against the top wire so he decided to pivot the whole thing up on one end to a vertical position so that gravity would work equally on both sides. A sketch of the whole idea with all the detailed mathematical and physics workings was then presented to the R&D committee of the Paper Machine Division of the Black Clawson Company at Watertown, New York. The Committee approved the project and C.C Lundegger, Assistant General Manager and Wes Cobin, were assigned the primary responsibility for the development of the Verti-Forma. A conception drawing was made and sent to Time-Life. Time-Life showed interest in the drawing so they requested a plastic model, which remained in their laboratory for 60 days. However, at that time Thoma informed Baxter that they had already made committments to other machine builders- it was 2 years since their first meeting (Black Clawson, 1968).

This news however did not discourage Black Clawson and an experimental machine was built and installed at Dilts, New York, on March 31, 1959. Preliminary tests were run using water only to check the hydraulics and in January, 1960, the machine was removed to Middletown, Ohio, where a new Corporate laboratory had been completed. More trials were carried out at Middletown first under Walt Rajecki and later Marshall Green and Fred Martin, and a number of engineering and design errors were corrected. Eventually, a sheet of paper was made. After further refinement, machine samples were sent to PAPRICAN, Point Claire and Syracuse University for testing. Both institutes reported that the sheet had identical surfaces.

A meeting held by Black Clawson, at the Syracuse University decided unanimously to go ahead with commercial production. The machine was transferred to the Old Taggart Mill in Watertown, where presses were added to enhance production and customers were invited to ship pulp samples to be run on the machine. During this time a search for prospective customers also began to be made and in September, 1966 work began with the Canadian International Paper (CIP) on the design, engineering and manufacturing of the first commercial development of the machine at Owen Sound, Ontario. In 1968, the machine started-up at the CIP's Trois Rivieres mill as the world's first commercial twin-wire for newsprint production.

The Development of the Papriformer

The development of the *Papriformer* began in 1959 (de Montigny et al, 1967; Atkinson and Maleshenko, 1971), when Ray de Montigny and his research team at PAPRICAN, Point Claire, Quebec began work on a different version of the twin-wire machine. The objective of this development was to improve the shortening wire life of the Fourdrinier wire and the smoothness and formation of the Fourdrinier paper. It was observed that for these objectives to be achieved, the early part of the drainage should be void of strong drainage pulses until the sheet was sufficiently formed to withstand the disturbance (Sankey, 1976). Thus a maximum feasible initial drainage length was envisaged, before a second wire was introduced. It was also recognised that to preserve good fibre distribution, the fibre should be trapped earlier. Finally, it was envisaged that an ideal former should occupy less space than the conventional Fourdrinier wet-end, allow easy and precise control of operating conditions and have high potential productivity to reduce capital and operating costs per potential ton of product (de Montigny et al, 1967).

A crude form of a twin-wire called *Mark I* was built to see if a web could be formed at the speed of commercial machines. Following the success of this experiment and with financial support from Dominion Engineering Works Limited of Canada, a *Mark II*, called *Demon* was built to test instrumentation drainage mechanisms. In 1960, PAPRICAN filed a US patent application on the Demon and Ray de Montigny exchanged ideas with Webster, who had refiled his 1953 abandoned patent application in 1959 (Merka, 1979). The performance of the *Demon* provided a lot of valuable information and to overcome its shortcomings, a paper machine incorporating some different principles and which later became the *Papriformer*, was conceived.

In 1964, a patent application on the Papriformer was filed and in 1965, the first full-experimental prototype of the machine, began operation at the Institute. PAPRICAN licensed Dominion Engineering Works (DEW) of Canada and KMW of Sweden, who were also interested in the Papriformer principles, to manufacture and sell the machine: Dominion having exclusive licence in North America up to December 31, 1972 and KMW similar exclusive rights in Europe. Thereafter, either company had the right to manufacture and and sell anywhere. In 1972, the first commercial prototype of Dominion's Papriformer was approved for installation at the Kruger Pulp and Paper Limited, Bromptonville, Canada.

The Development of The Bel Baie

The next development in the search for twin-wires came from the Beloit Corporation of Wisconsin, when Joseph Parker toiled with a concept which later developed into the *Bel Baie* twin-wire machine. The machine, which was a joint venture between Beloit and Ontario Paper's

Quebec North Shore (QNS) mill at Baie Comeau, was originally designed to enable the mill to go back to the conventional Fourdrinier in 48 hours. As such an 18-inch model, which was assembled at Beloit in 1968, under the direction of E. J. Justus, the then Vice-President of Research at Beloit, still had the conventional Fourdrinier wire as part of the bottom wire of the machine. However in December, 1968 a decision was made by both parties to convert the machine into a twin-wire concept by reducing the length of the bottom wire from 153 feet to 94 feet. The result of the experimental work which was conducted with engineers and furnish from Baie Comeau proved favourable and in 1969, the first commercial installation was made at the mill. Further research immediately proceded on this new concept in 1969 and in 1972, a new develpoment of the original Bel Baie, the *Bel Baie II* was released with the first installation made by Jugo Paper in Japan.

The Development of The Periformer

The origin of the *Periformer*, the first twin-wire tissue machine, goes back to the work of Otto Brauns of the Central Laboratory of the Swedish Paper Mills (PCI now STFI). According to Norman (1979), Brauns was working on roll formers, just like Webster, and was probably doing so around the same time. In 1960, Brauns put in a patent application in Sweden and since Webster did not file any patent application in Europe, Brauns' application was granted without revealing any conflicting patent (Norman, 1979). [4] Brauns then established contacts with KMW, which was thinking on similar lines to apply the new ideas to industrial production. A Yankee cylinder paper machine was accordingly transferred from PCI to KMW for use in experiment on tissue roll forming. However, when Brauns applied for a US patent application Webster's ten-year old application was revealed and in 1963, Brauns had to give up the patent fight. KMW, under the direction of Borge Walshtrom, however, went ahead to secure an exclusive licence and continued with the development of the machine. In 1970, an earlier version of the machine which came to be called the *Periformer*, started-up in Friesland, Holland. This earlier version was a single-wire machine for

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4. No conflict was revealed because Webster did not file any patent application in Europe.

tissue production and in 1975, the first twin-wire version started up at Fiskeby AB's Katrinefors mill in Sweden as the first twin-wire tissue machine (Kalish, 1975).

The Era of The Hybrid Formers

In two main respects, the development of *hybrid* formers offers a very interesting case of the development of the twin-wire technology. First, it constitutes a clear evidence of significant departures from the general trajectory of change that is possible in major technological developments. Second, it shows how spatial and temporal differences in conditions prevailing in the origins of the major technological developments can influence and direct the pattern and course of technological change.

With the exception of the Periformer, the first generation of modern twin-wires for paper grades other than board, were all developed in North America. Apart from their origins, a characteristic feature of these machines was that they had very good formation but their *first-pass retention* was very poor. [5] From engineering point of view, formation and retention are two aspects of the paper machine which cannot be maximised at the same time and therefore their consideration in the design of machines always involves some kind of trade-off.

The prevailing conditions in North America at that time made the balance in this trade-off tip in favour of formation. First, the drive towards higher quality paper naturally required paper with good formation. Second, the abundant and cheap supply of wood fibre in North America had not yet made loss of fines during the sheet-forming process a matter of extreme concern to paper companies. Third, relative low population density coupled with enormous amount of water resources had delayed the pressure on pulp and paper companies to be pollution-conscious and therefore made it much easier for pulp and paper mills to dispose of fines that got thrown out during the

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5. Retention measures the amount of fines that can be retained in the sheet during the forming process. If more fines get thrown out the retention is said to be poor or low.

sheet forming process. Finally, the then pressroom technology made the use of long fibre in paper-making more attractive.

In Europe, the context within which the trade-off between formation and retention could be made were different. First, with newsprint, European printing technology was changing faster than it was in North America. It was not only moving away from letterpress to offset printing but as a result European newspapers were going down in basis weight. With printing and writing paper grades high quality smooth surface, good formation, closed sheet (low porosity), absence of pinholes, high opacity coupled with some brightness were required. Intensive research in the 1960s showed that all these could best be achieved by using short fibres in addition with mineral fillers, particularly clay. The problem however was that a mixture of fibre and clay led to poor fiber retention. The result was that even though clay was cheaper than fibre in Europe, faced with diminishing fibre resource, it was necessary that European pulp and paper industry maintained a reasonable level of retention of fines during the sheet-forming process.

Second, the European pulp and paper industry was faced with a much bigger environmental problem than their North American counterparts for two reasons. The first reason was simply that Europe was more populous than North America and the second reason was that Europe had only few big rivers, many of them being indeed streams by North American standards, to serve as outlets for pulp effluent. European Pulp and Paper mills therefore came under greater pressure to dispose of their waste than their North American counterparts. Indeed, as a result of this most European mills had to develop large circling pumps for their effluents, where they would keep and redrain them successively till they got to a stage where they could be reduced and used as soil improvers.

As a result of these conditions, when European machine builders joined the search for an alternative to the Fourdrinier paper machine at the beginning of the 1970s, they were much more concerned about retention than formation, even though they sought to develop machines with better formation than the Fourdrinier (Jones, 1988). From the North American developments, it was realised that the reason why the early twin-wires had poor retention rate was due to the fact that the two-sided dewatering process began too early in the forming process. It was therefore realised that if the web was allowed to form first by dewatering through only one side before introducing a second wire for a two-sided dewatering, the retention of fines would be improved. Thus the hybrid twin-wire versions were designed.

The first of these machines was the Valmet *Sym Former F*[6]. The initial idea occurred in 1970. Discussion went on for about one year. In 1972, a pilot plant model was built and tried and in 1973 the first commercial delivery was undertaken. About the same time, Voith also came up with its first version, the *Duoformer C*[7]. However, the design of the machine was so similar to the Papriformer that it gave rise to patent problems. Subsequently the machine was taken out and a new design, making use of the Fourdrinier forming board concept, was developed. The result was the *Duoformer E*[8], which became available in 1975.[9]

Even though hybrid formers had been developed primarily to meet the needs of the European industry, a number world-wide developments during the first half of the 1970s made them attractive in the North America as well. First, the 1974 oil crisis hit the North American pulp and paper industry badly and pushed up prices of machinery. Second, increasing public concern about pollution forced pulp and paper mills to clean up by taking pollution control measures. This also meant additional cost. In Canada, in particular, these problems were exacerbated by industry-wide strikes which further increased production costs. With the rising cost of production and new machines and

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6. The F stands for fine paper.

7. C stands for compact.

8. E stands for Extended former

9. Both the Duoformer C and E are technically speaking not hybrid formers because the preforming sections in both machines were so short that the jet of stock was injected almost immediately between the two-wires, thus making them more of pure twin-wires than hybrid.

with the increasing demand for high quality paper these hybrids offered an opportunity for rebuilding existing Fourdrinier machines into twin-wires and were, in terms of cost, considered as the best alternative to installing completely new pure twin-wire machines. However, expenses involved in rebuilds soon proved to be prohibitive too. Apart from the new equipment, the re-build required extensive modifications to the entire wet end of the paper machine, including the building itself. In addition there was the matter of extensive downtimes (Malashenko 1983). Typically, the installed cost was up to two to three times the cost of the equipment itself, on top of which the mill lost revenue due to downtime. Many companies therefore opted to shut down their older machines altogether, while some converted them into speciality grades.

Clearly, what was needed was a less elaborate and much less expensive means of upgrading the Fourdrinier by combining the forming mechanism of an open wire Fourdrinier with that of a twin-wire former. Much earlier in 1971, a joint effort between Beloit-Walmsley and the Australia Paper Manufactures (APM) to improve upon the Inverform had resulted in the *Bel Bond* machine in 1973 after APM had gone ahead with further development work. Indeed in 1973 APM installed a commercial unit on their Fairfield No. 6 machine and subsequently installed several units. Like the Inverform, that version of Bel Bond was only for board grades and it was as expensive as the hybrid formers that had been developed for the other grades.

It was therefore left for Alex Malashenko of Dominion Engineering Works, Canada, to pioneer what is known today as top-wire formers, for paper grades other than board. The pioneering machine was the *Dynaformer*. The initial idea of the Dynaformer was conceived in 1976. However, due to the success of the Papriformer at that time, the idea did not receive much enthusiasm and support at Dominion Engineering. It was not until 1978, when key Papriformer orders were lost to other competitive units that the potential of the Dynaformer idea was fully understood. Dominion allocated a grant of $160,000 for further development of the idea. However, by that time, Malashenko had completed all the design work and a pilot model was ready to be tested. Since Dominion did not have any pilot plant one was rented from the Hyuck Research Centre in

Rensselear, New York for the trial tests, which were done during the 1980-1981 period. Following the analysis and documentation of the trial results, promotion exercises towards commercialisation began. The impact of the Dynaformer was tremendous: within weeks of the first publication in November 1981, the first commercial unit was sold in Japan. In 1982, the first North American unit was installed at Inland Empire Paper of Spokane, Washington, US. By December 1983, 11 had been sold world-wide.

Apart from the pulp and paper companies, the concept also found attraction among other machine builders. In 1978, Beloit decided to develop the Bel Bond to make it applicable for paper grades other than board. In 1979/1980, the first North American unit was installed at the MacMillan Bloedel mill at Powell River, Canada. Thus with its previous experience and much larger resources, Beloit was able to commercialise the new *Bel Bond* even before the first Dynaformer was sold. In 1981, the same year that the Dynaformer was publicised and the first unit was sold, Voith, who might have been working on a similar concept at the same time as Dominion, also released the *Duoformer H*. Valmet came out with the *Sym Former R*[10], which was very similar to the Dynaformer except for a forming shoe which was put into the design to improve formation.

The Era of Consolidation And Incremental Technical Changes

With the realisation that the trend towards the use of the twin-wire machine generated from pressroom demand for better quality paper, machine builders or suppliers had to keep track on what was happening in the pressroom, as well as in the paper market, to enable them to design machines that would meet the needs of the industry. This meant that once they had released their first models of machines, suppliers had to monitor the latest developments in pressroom technology and also be in close touch with their immediate customers, namely the paper companies, in order to

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10. R stands for rebuild

learn how their previous machines were performing technologically and in meeting market needs. In the process the main technological activities became dominated by "incremental" changes upon original models. These incremental changes largely depended on the strength of supplier-customer relationship, technical competence of the customer in making critical observations and suggestions for improvement in machine performance , and the ability of the supplier to respond to the observations and suggestions offered by the customer.

It happened that European machine builders were in a much better position, as far as these factors were concerned, than their North American counterparts. In particular, until 1986, Valmet of Finland was part of a big Finnish conglomerate which included some pulp and paper companies. Similarly, Voith had, for a long time, worked closely with such big companies as Haindhl in the Federal Republic of Germany (FRG). This close association with paper producers aided European machine builders to improve upon their earlier models at a faster rate than their North American counterparts. Thus while the original *Sym Former F* was released in 1973 by 1975, an improved version, the *Sym Former N*, had been developed for newsprint production. The original model, the *Symformer F* had a short preforming section before the top wire was introduced. This design was good for low speed production. However, as customers tried to make higher quality newsprint with fillers the slow drainage made good formation difficult to achieve. As a result of these observations and subsequent suggestions from customers, the preforming section was lengthened to allow for more drainage before the top wire, hence the *Symformer N*. Similarly, Voith released the *Duoformer E,* and *F* in 1975 and 1976 respectively both of them as improvement upon the original Duoformer C following recommendations from local customers.

In contrast, the relationship between paper makers and machine builders in North America in the 1970s was not so close at that time. The two parties operated more independently of each other. Further technological developments in North America therefore came to depend largely on supplier initiatives, which in turn depended on availabilty of financial and competent human resources.

In the case of Black Clawson, this initiative was directed towards the pulping sector of the industry because of problems encountered in its initial attempt to improve upon the *Verti-Forma*. The shooting of the jet vertically down created a wedge, the end of which became rounded due to wire tension. This caused a lot of fines to be thrown out during the sheet forming process, which led to good formation but very poor retention and subsequently a big problem with cleanliness. An initial attempt was made to improve upon the machine by transforming the vertical *I* model into a *J* model. However, there were two other problems that were beyond the control of the company. First, a number of supporting developments had to be in place before commercialisation of the twin-wire technology could get underway. These included developments in headboxes, wire fabrics and deflector blades, particularly for blade formers. It happened that the wire fabrics at that time were not very good. They had shorter lifetimes and this was worsened by the dirt accumulation of the Vert-Forma. Besides, as a blade former, the Verti-Forma used deflector blades as the elements over which the dewatering process took place. Until 1982 when ceramic blades were first manufactured, these blades were made of stainless steel. Unfortunately, stainless steel blades did not last and could also become blunt and therefore unable to perform efficiently. In short, the necessary support system needed to make the Verti-Forma a good machine were not available at that time. The result was that initial attempts to improve the machine resulted in heavy financial drain and the Company turned its attention to building pulp plant machines. Indeed from 1975 to 1979/1980, nothing was done on the Verti-Forma and this greatly affected contacts with former customers.

For its part, Dominion had problems with maintaining the staff and resources required to develop its machines, namely the Papriformer and the Dynaformer. These problems had their origins in the mid-1950s, when General Electric (GE) bought into the company. Even though GE did not buy control, they took over a substantial section of Dominion. Since GE was more interested in hydraulics a greater part of Dominion's resources were diverted into hydraulics to the detriment of the Paper Machine Division at Lachine. Dominion therefore had to rely heavily on PAPRICAN, for its paper machine research. As a result of this lack of sufficient funds to employ and maintain highly competent staff and support R&D activities, Dominion could neither improve the Papriformer nor the Dynaformer.

The only North American machine builder that was active in improving its machines was Beloit. However its unsuccessful attempts to diversify into other areas such as railroad, insurance and farming during the late 1970s and early 1980s led to heavy financial drain on the company (Patrick, 1986). After the development of the Beloit Tissue former in 1976, there was not much activity in the paper machine area until 1982, except the application of the Bel Bond to paper grades.

From 1968, when the first Verti-Forma was installed, to about 1978 these conditions did not have much impact on supplier strategy because the paper machine market was highly regionalised: North American market were largely supplied by the North American machine builders, Beloit, Black Clawson and Dominion, while the European market was largely supplied by Valmet, Voith and KMW as well as other minor machine builders such as Escher Wyss. However, about the early part of the 1980s it was becoming clear that European paper machine builders were forging ahead of their North American counterparts in paper-making technology. Confident in their competitive strength, European paper machine builders decided to attack the North American market, a clear example of Brown's (1975) market and infrastructure model of innovation diffusion, and in the process some acquisitions and mergers took place. KMW of Sweden and Escher Wyss of Germany located in the US in the early 1980s by establishing marketing and service agencies in Charlotte, South Carolina and Appleton, Wisconsin respectively. Valmet of Finland bought Dominion Engineering in 1984 and KMW in 1986 and so established a base in both Canada and the US. Voith also purchased the Paper Machine Division of Allis Chalmers and established a base in the US in 1984. In 1985, it established a marketing and service office in Ottawa, Canada. Later in 1986, Beloit itself underwent a change of ownership when it was purchased by the Harnischfeger Corporation of Wisconsin.

The moves by the European machine builders into North America speeded up the resurgence of activities from the North American machine builders which had shortly begun after the beginning of the 1980s. Given their old strategy of good formation they now with attempted to improve retention, and to work more closely with paper makers. Beloit intensified its R&D activities on both new machine concepts and concepts which had been "lying idle" for some years. The results paid off. At the request of the Bowater Corporation for a top wire machine which had no vacuum, no drive, no ceramics and no speed limitation, the *Bel Roll* hybrid former was built and installed in 1983. Unfortunately, the machine turned out to be a very poor one, with inferior sheet quality. Besides, the machine could not be adjusted and with the exception of Oji Paper of Japan, only Bowater installed seven of them in their mills. To replace the Bel Roll, the *Bel Form* , which became available in 1984, was designed to consist of the strong designed features of all three Beloit machines, the Bel Baie, the Bel Bond and the Bel Roll. From the Bel Roll it inherited the *centre roll,* from the Bel Bond, the *auto slice* and from the Bel Baie, *the forming shoe.* The Bel Form thus combined both static and roll forming elements and soon became the Beloit's best hybrid former for price. Between 1982 and 1984, intensive R&D work was carried out on the *Bel Baie III*, which had been conceived as far back as 1975 (Table 4.2) to improve the sheet quality and the retention of the Bel Baie II. In 1984, the first commercial unit started up at the Ortviken mill of Svenska Cellulose AB (SCA), Sweden.

With the development of ceramic blades in 1982 and improvement in wire fabrics, Black Clawson took advantage of the situation and began to work closely with Consolidated-Bathurst, an old customer, to reduce the problems of the *Verti-Forma J*. The result of this effort was the *Verti-Forma V* which, unlike the *I* and *J* models, had its headbox located below the machine. The first one was installed at the Consolidated-Bathurst Wayagamack mill at Trois Rivieres. Similarly, following the initiative of Abitibi-Price, Black Clawson entered the top wire market with *Top Flyte* in 1982. The first one was installed by Abitibi-Price and quickly the Top Flyte became the top wire with the best formation.

Realising that the North American market preferred machines with good formation to good retention, both Valmet and Voith decided to respond by changing their designs. Based on the Symformer R concept, Valmet came out first with a new machine called the *Symformer* and Voith the *Duoformer FM* and the *Duoformer NM*. Beloit released the *Horizontal Bel Baie III* in 1987. Black Clawson continued its Top Flyte and came out with *Top Flyte 'C'*. Valmet responded with the *Speedformer HS*[11] while Voith put out the *Duoformer CF*.[12] The Valmet *Speedformer HS* was similar to the Horizontal Bel Baie III that some patent litigations had to be resolved between Beloit and Valmet. Thus by 1987, the single Verti-Forma which was installed in 1968 had multiplied into several twin-wire versions all of them in active production in various areas of the industry. What then is the relevance of these developments to understanding the diffusion of the twin-wire technology?

The Relevance of Technological Context

The relevance of the technological context just examined to the diffusion of the twin-wire technology lies in how the research and development (R&D) process of the twin-wire influenced the choice of the twin-wire paper machine. First, R&D activities increased the product range pattern to which the twin-wire could be applied. The Verti-Forma was primarily geared towards newsprint production.[13] In 1971, the Bel Bond pioneered the twin-wire board-making. In 1972, with the development of the Periformer, the twin-wire tissue production was launched and in 1973, the Sym-Former F ushered in the twin-wire era for the printing/writing paper grades (Fig 4.1). Thus, while in 1968 the only twin-wire machine was for newsprint production, by 1988 only 42 per cent

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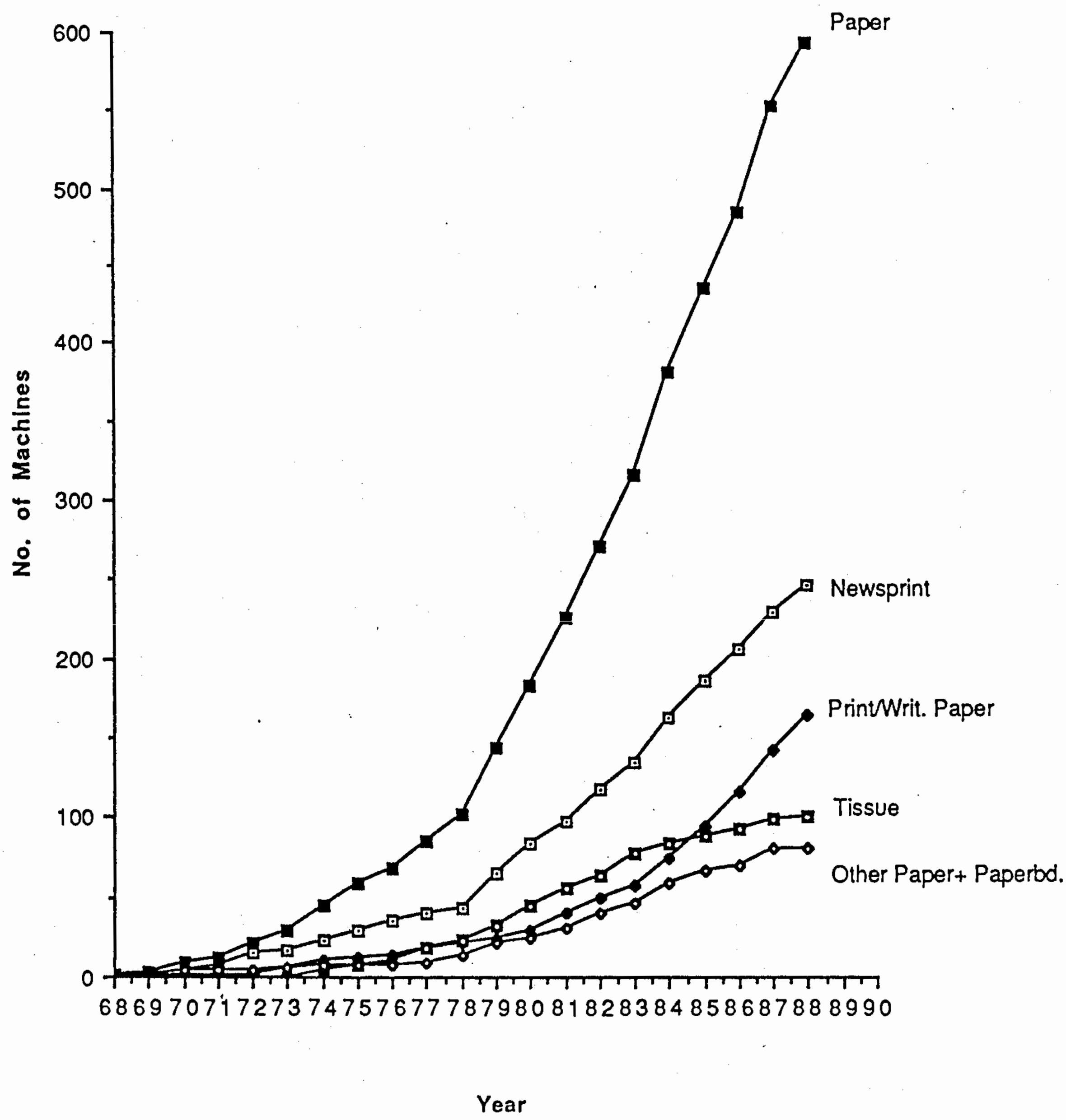
11. HS stands for high speed

12. This former was at first called Duoformer 2000F.

13. Actually, the Verti-Forma was versatile in application from the beginning. The first commercial unit had the capability of producing both newsprint and groundwood specialities. In 1970, it was applied to the production of fine paper. However, it was not until the coming of the Sym-Former and other hybrids that twin-wire applications in the printing and writing paper became a 'universal' reality and as of 1988, almost all the fine paper grades in the industry were produced on hybrid formers.

FIG. 4.1: WORLD TWIN-WIRE INSTALLATIONS, 1968-1988



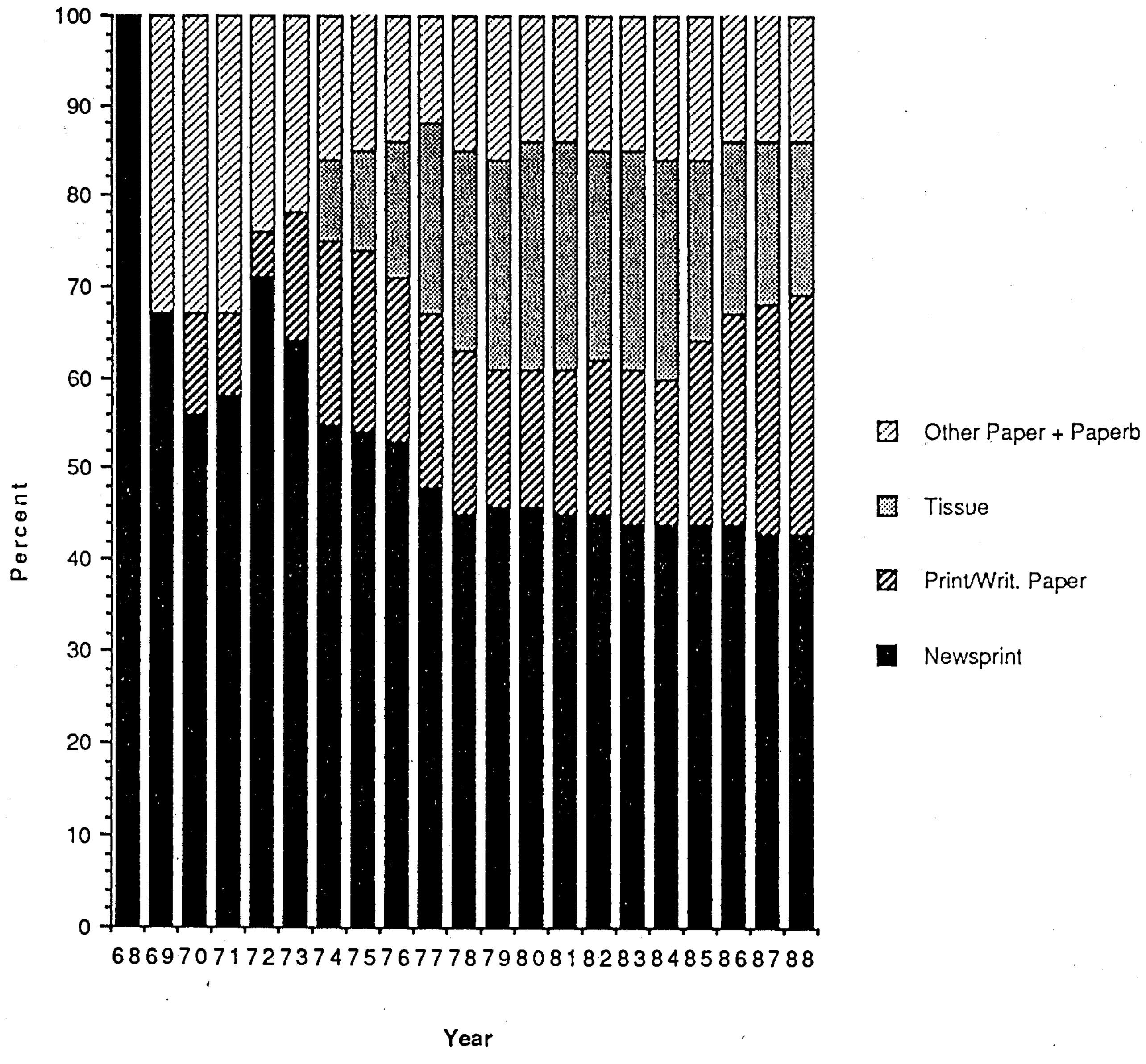
Source: Installation lists of Twin-Wire Manufacturers and Pulp and Paper International's Twin-Wire Survey.

of the total number of the 592 twin-wire machines were devoted to newsprint while 28 per cent were in printing/writing paper production, 17 per cent in tissue and 14 per cent in other paper and board (Fig 4.2).

Second, the R&D activities not only widened the product range of the twin-wire technology but also the category of machine and as well as the different types of units. Between 1968 and 1972 only "pure" twin-wires existed. By 1988, there were 339 top wire or hybrid constituting 57 per cent of the total twin-wires (Fig. 4.3). Examination of the yearly installations shows that this change has largely occurred since 1979. In that year, the proportion of top wire installations reached 20 per cent of the total installations. In 1988 top formers accounted for 59 per cent of the total installations made in that year. Economically, these top wires were less expensive since firms did not have to dispose of the ancillary parts of the paper machine which were very expensive. By retrofitting them on the Fourdrinier, the top wires made it possible for firms to rebuild their existing Fourdriniers into twin-wires without necessarily disposing their old machines.

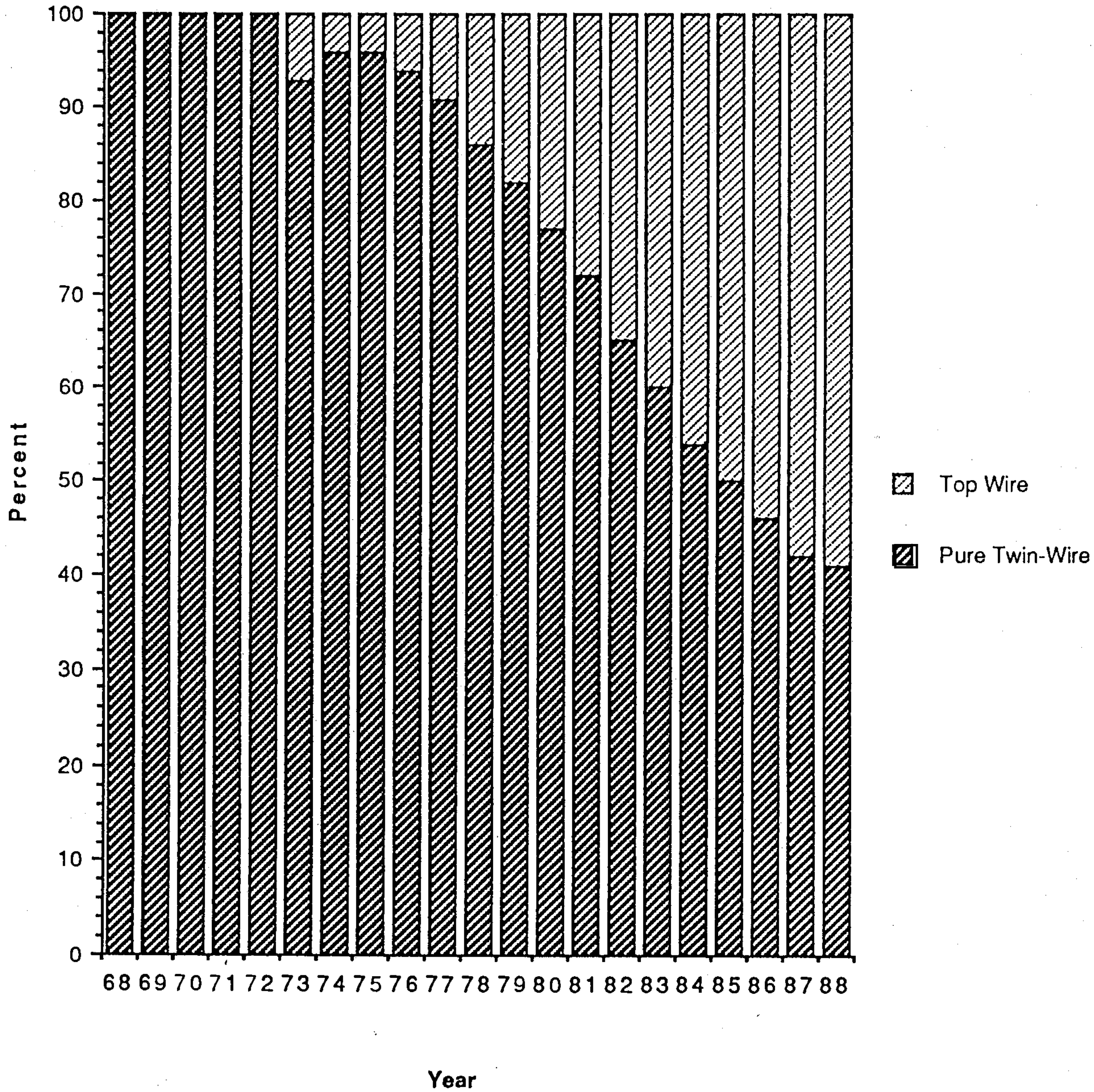
With respect to type of units, the technological developments also made it possible for a whole range of units to be developed, each with a distinctive feature and characteristics. The Verti-Forma, developed into the models J and V. Other rival units in the newsprint sector were the Papriformer, the Bel Baie I, II and III, the Sym-Former N and R, the Duoformer C and H. In printing/writing paper, the Sym-Former F developed into the FR and FM models while other units like the Duoformer F and FM, and the Top Flyte were also developed. In tissue the Duoformer T and the Beloit Tissue became other competing units to the Periformer while in other paper and board, the Duoformer D and K became alternatives to the Bel Bond. Indeed as of 1988, most of the twin-wires in operation were so versatile that at least they could be used to produce two different grades. These different units widened the range of choice for the paper manufacturers to enable them make proper and well-informed choices.

FIG. 4.2: PERCENTAGE TWIN-WIRE INSTALLATIONS BY GRADE, 1968-1988



Source: Installation lists of Twin-Wire Manufacturers and Pulp and Paper International's Twin-Wire Survey.

FIG. 4.3: TWIN-WIRE INSTALLATIONS BY CATEGORY OF UNIT



Source: Installation lists of Twin-Wire Manufacturers and Pulp and Paper International's Twin-Wire Survey.

Third, the technological developments of the twin-wire also affected the Fourdrinier. In a way, they brought pressure to develop and improve the Fourdrinier to its limits. Indeed Sinkey and Wahren's (1985, 1986) review and summary of a number of studies conducted into the performance of the Fourdrinier and the twin-wire indicate that the Fourdrinier is still strong in some aspects of paper production (Table 4.3). Thus, it has been established that the Fourdrinier paper has a better porosity that the twin-wire paper. In addition, the Fourdrinier has a higher retention rate when compared especially to blade formers. However, as Table 4.3 indicates, most of the results are supportive of the twin-wire's superiority over the Fourdrinier. First twin-wires, as a group have been found to perform better than the Fourdrinier in terms of fibre control, formation, sheet strength, reduction of two-sidedness and reduction in basis weight. In addition, top wires are lower-energy consumers than Fourdriniers (Harwood, 1987). Besides, twin-wires generally have much higher speed than Fourdriniers For these reasons, they are much more suitable in the production of bulk grades such as newsprint, where increasing production with minimum energy requirement is very important to minimise production cost.

There are interesting national patterns in twin-wire evolution and development. Thus, it can be seen that, apart from Canada and Sweden, countries which had capabilities in twin-wire manufacture also tend to use their own machines (Table 4.4). Even in the case of Canada, we can see that machines of Canadian origin ranks next to those with US origin. Sweden is an exception because the machine in which it had the technological capability turned out to be a tissue machine which had not been its traditional speciality. Detail analyses of the diffusion period are provided in Tables 4.5, to 4.8. In the case of Finland, for example, four machines were installed in the 1968-1973 period: three were of US origin, and one was Finnish (Table 4.5). Between 1974 and 1978, only one twin-wire unit of Finnish origin was installed (Table 4.6). From 1979 to 1983, 17 units were installed 15 of which were Finnish in origin (Table 4.7). From 1984 to 1988, 8 machines were installed; all were Finnish (Table 4.8). In the case of FRG, no twin-wire units were installed from 1968 to 1973 (Table 4.4). During the 1974 to 1978 period, 3 units were installed, of which

Table 4.3: **Comparison of Some Quality Characteristics Between Twin-Wires And Fourdriniers**

	Roll Formers	Blade Formers	Dewatering Over Rolls	Stationary Element
Formation	+	++	+/++	++
Strength		O/+	O/+	O/+
Bulk	O/+	O/-	O/+	O/-
Two-sidedness	+/++	++	+/++	++
Linting	+/++	++	+/++	++
Smoothness	+	+	+	+
Porosity	-	O/-	-	O/-
Pinholes	O/-	++	+	++
Basis weight profiles	+	+	+	+

++ = substantial improvement over Fourdrinier
+ = slight to moderate improvement over Fourdrinier
O = no significant or consistent effect
- = slight to moderate deterioration relative to Fourdrinier

Source: Sinkey and Wahren, 1985, 1986

Table 4.4: **Twin-Wire Use In Countries Which Originally Developed Twin-Wire Versions, 1968-1984**

Machine Originated By	Machine Used By: Canada	Finland	FRG	Sweden	US	Total
Canada	10	-	-	-	5	15
Finland	20	25	4	11	12	72
FRG	2	-	25	4	12	43
Sweden	4	-	1	6	14	25
US	67	5	2	19	79	172
Total	103	30	32	40	122	327

Table 4.5: **Twin-Wire Use In Countries Which Originally Developed Twin-Wire Versions, 1968-1973**

Machine originated by	Machine Used By: Canada	Finland	FRG	Sweden	US	Total
Canada	2	-	-	1	-	3
Finland	-	1	-	-	-	1
FRG	-	-	-	-	-	
Sweden	-	-	-	-	-	
US	6	3	-	-	3	12
Total	8	4	-	1	3	16

Table 4.6: **Twin-Wire Use In Countries Which Originally Developed Twin-Wire Versions, 1974-1978**

Machine originated by	Machine Used By Canada	Finland	FRG	Sweden	US	Total
Canada	4	-	-	-	4	8
Finland	-	1	1	1	-	3
FRG	-	-	1	2	1	4
Sweden	1	-	-	3	8	12
US	2	-	1	5	8	16
Total	7	1	3	11	21	43

Source: PPI Twin-Wire Survey, 1984; Author's Survey.

Table 4.7: **Twin-Wire Use In Countries Which Originally Developed Twin-Wire Versions, 1979-1983**

Machine Originated By	Machine Used By Canada	Finland	FRG	Sweden	US	Total
Canada	4	-	-	-	1	5
Finland	5	15	2	6	5	33
FRG	1	-	12	1	1	15
Sweden	3	-	1	3	6	13
US	15	2	-	4	32	53
Total	28	17	15	14	45	119

Table 4.8: **Twin-Wire Use In Countries Which Originally Developed Twin-Wire Versions, 1984-1988**

Machine Originated By	Machine Used By Canada	Finland	FRG	Sweden	US	Total
Canada	-	-	-	-	-	-
Finland	15	8	-	4	7	34
FRG	1	-	10	1	10	22
Sweden	-	-	-	-	-	
US	44	-	1	8	36	89
Total	60	8	11	13	53	145

Source: PPI Twin-Wire Survey, 1984; Author's Survey.

two were of German origin and the other was Finnish (Table 4.6). From 1979 to 1983 15 units of twin-wire machines were installed and 12 of them were German origin (Table 4.7). In the US the picture is not different except that more twin-wire units of Swedish origin were adopted in the 1974 to 1979 period. However, as we have already pointed out, all these installations were the Periformer tissue machine.

Even in Canada and Sweden, where firms have adopted machines developed developed by all the major manufacturers, there is some evidence of the above observation. In Canada, for example, 8 twin-wire units were installed during the 1968 to 1973 all being American in origin. In 1974-1978, the period during which PAPRICAN's Papriformer had been successfully commercialised, the same number of units were installed but this time four were of Canadian origin, three US and one Swedish (Table 4.6). It is interesting to note that the one unit of Swedish origin and one of the three US units were tissue machines for which Canada had not developed any capability. In 1979-1984, 28 units were installed: four were Canadian in origin, five were Finnish, three Swedish and 15 American (Table 4.7). This was the period when as a result of the agreement reached by PAPRICAN, with KMW of Sweden and Dominion Engineering Works of Canada, the manufacturing of PAPRICAN's Papriformer was solely in the hands of KMW.

In the case of Sweden, only two twin-wire units were installed from 1968-1973 and both were of US origin (Table 4.5) From 1974 to 1978, nine units were installed of which three were Swedish in origin , two were German, three American and one Finnish (Table 4.6). For the 1979-1983 period, 14 units were installed of which three were Swedish, one German, six Finnish and one American (Table 4.7). Again this pattern might be expected considering the fact that the the Periformer, which is the twin-wire unit of Swedish origin was for the production of tissue only. Another pattern which emerges out of this analysis, is where the machines used are not of national origin, they have mostly come from nearby nations such as machines of American origin in Canada, or machines of Finnish origin in Sweden. To sum up, there is a tendency for pulp and paper firms to be "nationalistic" regarding the twin-wire machines they want to install. This means that the timing of when a country acquires the capability of building its own version of the technology becomes important to understanding the number of units adopted and the timing when the adoption takes place.

Conclusion

The development of the twin-wire paper machine was motivated by the demand for higher quality paper and the need to increase production to meet the needs of the paper market. The research and development process of the technology was largely conducted by the paper machine manufacturers. Different market situations that these suppliers had to address defined certain technological trajectories within the broad paradigm of the twin-wire technology. As national capabilities of twin-wire technologies emerged the pattern of adoption also became affected even as firms became more "nationalistic" (except for Canada and to a large extent Sweden) This greatly influenced the timing of adoptions. With the passing of the first stage of machines, competitive strategies of suppliers became more and more important as suppliers embarked on incremental technical changes and horizontal integration to gain a niche in the market. These activities increased the range of choice of the technology, the range of products to which it could be applied and greatly improved the technology's quality performance over and above the old one, namely the Fourdrinier.

In Canada, these developments were of significance to the choice of the twin-wire technology. As the world's leader in newsprint export trade, the development of the twin-wire was very crucial for its newsprint industry. Thus, it was the first country to adopt the twin-wire technology. The development of the technology from outside the pulp and paper industry also meant that right from the beginning supplier strategy would be the driving force regarding the flow of information about the technology. Thus the machine which was first installed in Canada was developed in the US. The achievement of national capability in the early stages of the development of the twin-wire technology was also relevant for Canada in providing an opportunity for innovative Canadian firms to take an early lead in the adoption of the twin-wire technology. Finally, supplier strategies of horizontal integration and incremental technical changes provided Canadian firms the opportunity to observe the latest developments in the technology in close physical proximity even at a time when Canada's twin-wire technological capability had began to decline. The R&D processes of a given technology have potentially important explanatory implications for the different adoptive behaviour. It holds a partial key as to why some firms are early, why some are late and why some do not adopt at all. It also holds a partial key to the bandwagon-effect of innovation diffusion. In the next chapter, the diffusion pattern that arose from these adoptions are examined within their spatial context.

CHAPTER V

THE SPATIAL CONTEXT

Manufacturing firms occupy distinct geographical locations or territories. As a result of competition and interdependence, the decision by one firm to adopt a new technology may over time be replicated by its competitors, either in the same location or elsewhere. In this case the diffusion pattern of an innovation, defined here as the distribution characteristics of the innovation, is an evolution of an *initial* diffusion pattern. If the world were homogenous, then the only feature of such a pattern that would differ would be time. In reality , however, this is not the case. Instead, the diffusion pattern of any given technology tends to show certain distinctive characteristic which are not only time-specific but also locational-specific. As indicated by the previous chapter, the very nature of technological development is even influenced by the regional context. Regions differ in resource endowments and production specialisations and agglomerations. These differences have implications for technology choice which, in a global industry, can be better understood by placing each region within a global context. Consequently, this chapter examines the global diffusion of the twin-wire and examines national variations with particular reference to Canada.

The data base for analysis is the Pulp And Paper International (PPI)'s Twin-Wire Survey, 1984. Among other things, the data consisted of a list of countries with twin-wire installations, the customer firms, start-up dates of the machines, the mill at which the installation was made, trim width of the machine, operating speed of the machine, capacity, the type of grades produced and the type of unit. In addition, a summary table of manufacturers and their twin-wire models as well as number of twin-wire units by country and by start-up year and grade were also given. Other data and information on firm characteristics were obtained from 1968 to 1988 issues of Lockwood's Directory, Moody's Industrial Manual and Pulp And Paper Canada Directory and some publications of Statistics Canada.

Readers, however, should take note of several difficulties that were encountered with the data. First, the PPI's Twin-Wire Survey 1984 was the last ever to be conducted. In order to be consistent with the time frame selected for the thesis, it became necessary to update the data. To do this all the 8 twin-wire manufacturers indicated on the PPI Twin-Wire Survey list were contacted. Four responded. Of the four that did not respond, two had been bought out by one of the four respondents. The other two were minor manufacturers. This means the actual number of twin-wire machines running by the end of 1988, that is the end of our study period, is slightly more than the total number mentioned in the chapter. This small deficiency, however, is not thought to affect the analysis. Another problem in updating the data concerns timing. Some of the manufacturers used the year of supply while others used the start-up date (as did the PPI data). To maintain consistency, careful comparisons were made between the PPI data and the installation lists and some estimates based on the length between delivery and final installation of machine were made. Information on 6 installation listings was incomplete so they were excluded from the analysis. Some inconsistencies were also found among the sources of information on firm characteristics, particularly with the number of pulp and paper firms and plants in Canada. In addition, the available statistics from these directories do not make distinctions between firms that produce only market pulp and firms that produce only paper or both pulp and paper. These affected the calculation of proportions and other measures used in the analysis. However, the effects of these shortcomings on the purpose of this chapter is only marginal and relevant notes and further caution are given later on in the texts where necessary.

This chapter is in five sections. After a brief description of some of the common measures of diffusion pattern used in the analysis, the twin-wire diffusion pattern is explored at three main scales: the global scale, national scale and local scale with special attention to Canada. The final section examines the extent to which the spatial context helps the understanding of technology choice.

Some Common Measures of Diffusion Pattern

A number of measures have been developed in conventional diffusion studies to describe and or predict certain aspects of diffusion pattern that are of interest such as intensity and coverage. Among these measures are proportion-of-user measures, diffusion lag, and diffusion rate. In addition, I propose a new measure called the average per unit frequency of installation or usage or "adoption". I will discuss each of these measures before we attempt to calculate their equivalent values on our global diffusion.

The Proportion-of-Users Measures

The proportion-of-users measures are a set of simple descriptive measures which gives the proportion of users of the innovation, the twin-wire in our case, among the potential population of users. It can be calculated on any group of users depending on the objectives of the study. Examples are the proportion of the total number of firms or plants using the innovation; the proportion of total output produced by the innovation; proportion of total stock of technologies for the production is accounted for by the innovation. For descriptive purposes, these measures, in all their various forms, give a better picture of the intensity and coverage of diffusion than ordinary numbers of users. However, as proportions, they are very sensitive to small number-base effects and can sometimes lead to superflous conclusions, when comparing situations with large and small number bases. Besides, they can only be calculated if the total numbers of the so-called "potential" users are known.

Diffusion Lag

Diffusion lag, defined as the length of time it takes an innovation to spread among other users after the first introduction of the innovation, is the simplest measure for finding how fast an innovation spread among a given group of users. The year in which the innovation was first introduced is usually taken as the base year and it is subtracted from the years in which subsequent users accept the innovation. In order to make for easy identification of new users, only first adoptions are usually considered in each case. The average of these individual lags is usually referred to as the *mean diffusion lag*. As in the case of the proportions, the mean diffusion lag can be calculated on any group of users.

The mean diffusion lag is a good measure if we are interested in how long it takes the innovation to get from the innovator to every subsequent user because it assumes that every subsequent user will pick up the innovation from the innovator alone. Without making adjustments for the possibility that subsequent users may pick up the innovation from one another, the total diffusion lag which produces the average can be meaningless due to the effect of double counting.

The Rate of Diffusion

The most widely used measure of diffusion is the diffusion rate or "adoption" rate, which measures the amount of change in the number of users due to a unit change in time. Since this measure is than the slope of the diffusion curve, the usual method for calculating it is to estimate the parameters of the diffusion curve, using the Mansfield's familiar equation

$$\ln [m(t) / n - m(t)] = \alpha + \phi t, \qquad (5.1)$$

Thus the rate of diffusion, ϕ, is the regression coefficient resulting from regressing the logarithm of the ratio of users who have already introduced the innovation to those who still have not, $\ln [m(t) / n - m(t)]$ on the time variable, t, measured in years.

As a measure, the rate of diffusion has the advantage over the other measures because it can be used to predict. However, to calculate it, we need to know the number of users, whether countries, firms or plants, that have already introduced the innovation at every period since the innovation was first introduced and the total number of potential users. Since this measure is also based on proportions the same practical difficulty of defining a population of "potential adopters" for some innovations or obtaining the appropriate data on global scale is encountered.

The Average Frequency of Acceptance (AFA)

The Average Frequency of Acceptance (AFA), is a new measure being proposed by this thesis and is defined as

$$D_t / N_u \qquad (5.2)$$

where D_t is the length of the diffusion period and N_u is the total number of users or installations during the period.

The improvement in this measure over the mean diffusion lag is that it adjusts for the possibility that users can pick up the innovation, not necessarily from the innovator, but from any other subsequent adopter. In addition, it provides a crude measure of the rate at which individual users accepted the innovation over the diffusion period. Like the proportion-of-users measure and the diffusion lag, the denominator in equation (5.2) can be any given group of users of an innovation, whether countries, firms, plants or even the mere numbers of the innovation that have been accepted. The principle of first adoptions, governing the calculation of proportion-of-users measures and diffusion lags do apply to this measure as well. However, this need not be the rule since a study of more than one adoption by a single user may sometimes be neccessary. For this reason, we define two types of AFA measures: one which does not adjust for first adoptions and the other which adjusts for first adoptions. For simplicity, we will call the former, the *unadjusted AFA* and the latter, the *adjusted AFA*. Finally, it is possible to calculate separate AFA values for distinctive sub-periods of the total diffusion period to examine the changes that have occurred in the frequency of use.

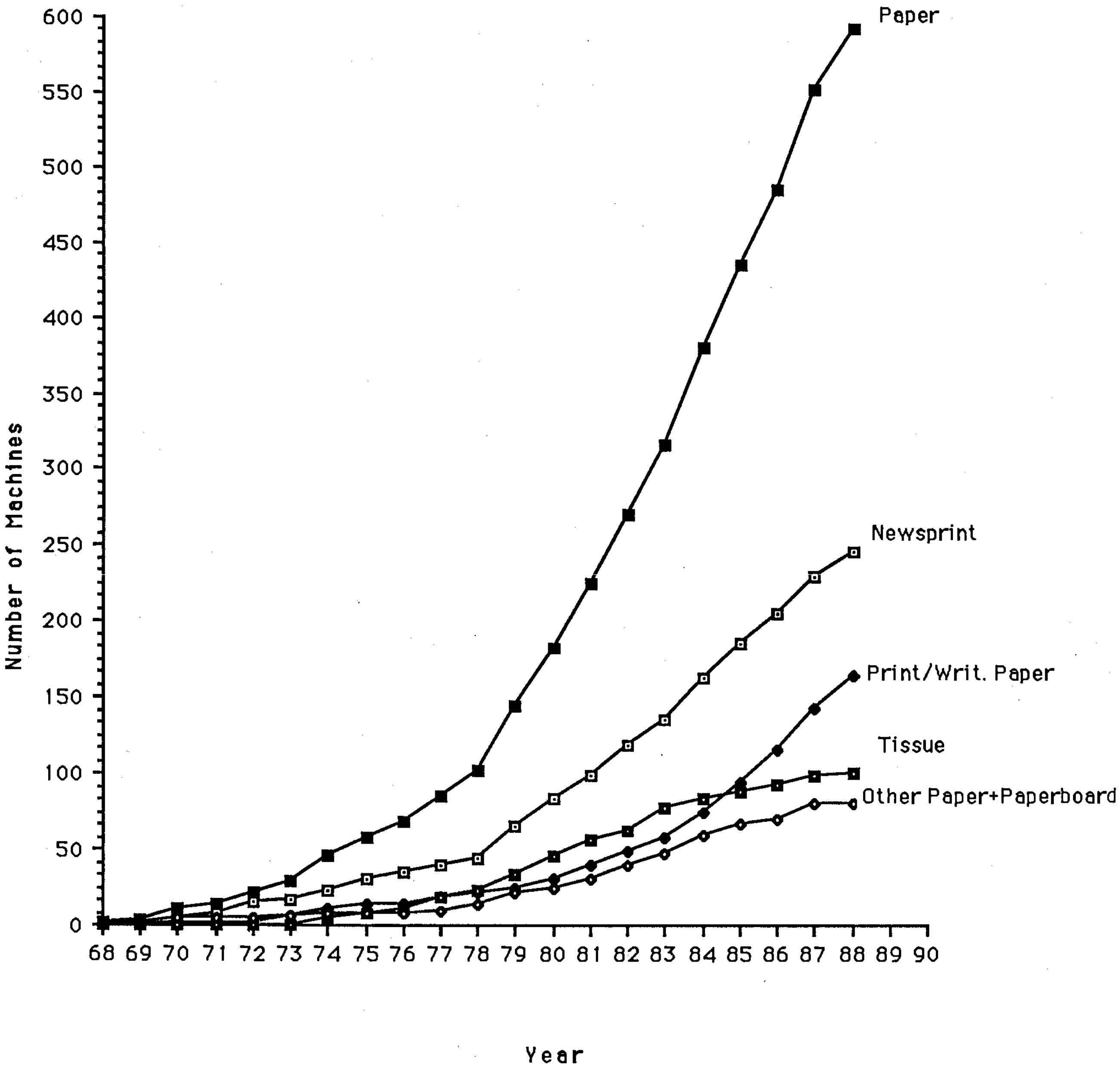
The Global Pattern

The Global Diffusion Curve

The first twin-wire paper machine was installed in 1968 in Canada. By 1988, there were 598 twin-wire machines in 46 countries. The global diffusion curve of twin-wire formers for all the paper grades referred to in the last chapter is reproduced here as Fig 5.1 and the distribution of the machines on the basis of the world's broad economic regions are also given in Tables 5.1 to 5.5 From the graph for the total paper grades, it is possible to distinguish between the first 10 years of the innovation, 1968 to 1978, during which a small number (17 per cent) of twin-wire formers were installed or adopted, and the second 10 years from 1979 to 1988, inclusive, during which the number installed by 1979 increased by 478 per cent to 590. From the tables, it can be seen that a greater part of the diffusion has taken place in the developed economies with the developing economies accounting for only a small proportion. From 1968 to 1973, for example, with the exception of two installations, one each in Brazil and Mexico, all the 29 installations were in the developed market economies (DMEs) (Table 5.1). By 1978 this concentration had not changed: 93 (90 per cent) of 102 twin-wires installed were in the DMEs with only 5 (5 per cent) in the developing market economies (DPEs) and 4 (4 per cent) in the centrally planned economies (CPEs). From 1979 to 1988 the pattern was the same. However, every region increased its stock of twin-wire installations. The DMEs increased their stock of twin-wire formers from 93 in the first 10 years of twin-wire's innovation to 517, an increase of 456 per cent. In the CPEs the number of installations reached 14 from 3, while the DPEs increased their number of installations from 5 to 39.

By category of twin-wire, there were 251 (43 per cent) pure twin-wires and 339 top wires (57 per cent) in 1988. Of the 251 pure twin-wires, 206 (82 per cent) were located in the DMEs, 15 (6 per cent) in the CPEs and 30 (10 per cent) in the DPEs. With respect to the top wires, the DMEs accounted for 311 (92 per cent) of the 339 total, the CPEs accounted for 9 (3 per cent) and the DPEs 19 (6 per cent) (Table 5.1).

Fig. 5.1: WORLD TWIN-WIRE INSTALLATIONS 1968-1988



Source: Installation lists of Twin-Wire Manufacturers and
Pulp And Paper International's Twin-Wire Survey

Table 5.1: **Distribution of The World's Twin-Wires By Economic Regions, 1968-1988**

	Developed Market		Centrally Planned		Developing Market		
	Pure Twin-Wire	Top Wire	Pure Twin-Wire	Top Wire	Pure Twin-Wire	Top Wire	Total
1968	1	-	-	-	-	-	1
1969	2	-	-	-	-	-	2
1970	7	-	-	-	-	-	7
1971	3	-	-	-	-	-	3
1972	9	-	-	-	-	-	9
1973	3	2	-	-	2	-	7
1974	15	-	-	-	-	-	16
1975	11	1	1	-	-	-	13
1976	7	1	1	-	-	1	10
1977	13	3	-	-	1	-	17
1978	8	6	1	1	1	-	17
1979	24	9	2	2	8	1	42
1980	19	14	0	0	2	0	39
1981	19	15	2	0	3	3	42
1982	14	26	0	2	2	1	46
1983	13	27	1	0	4	1	64
1984	8	48	1	0	5	2	54
1985	10	40	-	1	1	2	49
1986	5	40	2	-	-	2	49
1987	8	49	3	3	-	5	68
1988	7	30	1	-	-	1	39
TOTAL	206	311	15	9	30	19	590†

Source: PPI Twin-Wire Survey, 1984 and Installation lists of Twin-Wire Manufacturers.
†The data in the above Table do not include 2 twin-wires due to incomplete information.

Table 5.2 **Twin-Wires In Newsprint Production By Economic Regions, 1968-1988**

	Developed Market		Centrally Planned		Developing Market		
	Pure Twin-Wire	Top Wire	Pure Twin-Wire	Top Wire	Pure Twin-Wire	Top Wire	Total
1968	1	-	-	-	-	-	1
1969	1	-	-	-	-	-	1
1970	3	-	-	-	-	-	3
1971	2	-	-	-	-	-	2
1972	8	-	-	-	-	-	8
1973	2	-	-	-	-	-	2
1974	6	-	-	-	-	-	6
1975	6	-	1	-	-	-	7
1976	3	-	1	-	-	1	5
1977	4	1	-	-	-	-	5
1978	3	-	1	-	-	-	4
1979	12	2	1	2	4	-	21
1980	9	8	-	-	1	-	18
1981	9	4	1	-	1	-	15
1982	8	12	-	-	-	-	20
1983	4	13	-	-	-	-	17
1984	3	19	-	-	4	2	28
1985	3	18	-	-	1	-	22
1986	1	18	-	-	1	-	20
1987	3	18	-	-	-	3	22
1988	6	10	-	-	-	1	17
TOTAL	97	123	5	2	11	8	246

Source: PPI Twin-Wire Survey, 1984 and Installation lists of Twin-Wire Manufacturers

Table 5.3 **Twin-Wires In Printing/Writing Paper Production By Economic Regions, 1968-1988**

	Developed Market		Centrally Planned		Developing Market		
	Pure Twin-Wire	Top Wire	Pure Twin-Wire	Top Wire	Pure Twin-Wire	Top Wire	Total
1968	-	-	-	-	-	-	
1969	-	-	-	-	-	-	
1970	1	-	-	-	-	-	1
1971	-	-	-	-	-	-	-
1972	1	-	-	-	-	-	1
1973	1	1	-	-	2	-	4
1974	4	-	-	-	1	-	5
1975	2	-	-	-	-	-	2
1976	-	1	-	-	-	-	1
1977	2	1	-	1	-	-	4
1978	1	1	-	1	-	-	3
1979	1	1	-	-	-	1	3
1980	2	3	-	-	1	-	6
1981	2	6	-	-	-	2	10
1982	-	6	-	2	1	-	9
1983	-	8	-	-	-	-	8
1984	1	17	-	-	-	-	18
1985	1	16	-	1	-	1	19
1986	-	19	1	-	-	1	21
1987	2	22	-	2	-	1	27
1988	-	20	-	-	-	-	20
TOTAL	21	122	1	6	6	6	162†

†: Two twin-wire units are not included in this total because their start-up year and region were not published.
Source: PPI Twin-Wire Survey, 1984 and Installation lists of Twin-Wire Manufacturers.

Table 5.4 **Twin-Wires In Tissue Paper Production By Economic Regions, 1968-1988**

	Developed Market		Centrally Planned		Developing Market		
	Pure Twin-Wire	Top Wire	Pure Twin-Wire	Top Wire	Pure Twin-Wire	Top Wire	Total
1968	-	-	-	-	-	-	
1969	-	-	-	-	-	-	
1970	-	-	-	-	-	-	-
1971	-	-	-	-	-	-	-
1972	-	-	-	-	-	-	
1973	-	-	-	-	-	-	
1974	4	-	-	-	-	-	4
1975	3	-	-	-	-	-	3
1976	4	-	-	-	-	-	4
1977	7	-	-	-	-	-	7
1978	4	-	-	-	1	-	5
1979	9	-	1	-	-	-	10
1980	8	-	-	-	4	-	12
1981	8	-	1	-	2	-	11
1982	6	-	-	-	1	-	7
1983	9	-	1	-	4	-	14
1984	4	-	1	-	1	-	6
1985	5	-	-	-	-	-	5
1986	4	-	1	-	-	-	5
1987	3	-	3	-	-	-	6
1988	1	-	1	-	-	-	2
TOTAL	79	-	9	-	13	-	101

Source: PPI Twin-Wire Survey, 1984 and Installation lists of Twin-Wire Manufacturers.

Table 5.5 **Twin-Wires In Other Paper Production By Economic Regions, 1968-1988**

	Developed Market		Centrally Planned		Developing Market		
	Pure Twin-Wire	Top Wire	Pure Twin-Wire	Top Wire	Pure Twin-Wire	Top Wire	Total
1968	-	-	-	-	-	-	
1969	1	-	-	-	-	-	1
1970	3	-	-	-	-	-	3
1971	1	-	-	-	-	-	1
1972	-	-	-	-	-	-	
1973	-	1	-	-	-	-	1
1974	1	-	-	-	-	-	1
1975	-	1	-	-	-	-	1
1976	-	-	-	-	-	-	-
1977	-	1	-	-	-	-	1
1978	-	5	-	-	-	-	5
1979	2	6	-	-	-	-	8
1980	-	3	-	-	-	-	3
1981	-	5	-	-	-	1	6
1982	-	8	-	-	-	1	9
1983	-	6	-	-	-	1	7
1984	-	12	-	-	-	-	12
1985	1	6	-	-	-	1	8
1986	-	3	-	-	-	-	3
1987	-	9	-	1	-	1	11
1988	-	-	-	-	-	-	
TOTAL	9	66	-	1	-	5	81

Source: PPI Twin-Wire Survey, 1984 and Installation lists of Twin-wire Manufacturers.

By product, 246 (42 per cent) of 590 installations that could be categorised according to the information in Table 5.2 were devoted to newsprint production, 28 per cent in printing and writing paper, 17 per cent in tissue and 14 per cent in other paper and board. Of the 246 twin-wires in newsprint production, 220 (89 per cent) were located in the DMEs, 3 per cent in the CPEs and 8 per cent in the DPEs (Table 5.2). The distribution of twin-wires in the production of the other paper grades are given by Tables 5.3, 5.4 and 5.5. Thus in the DMEs and also in the DPEs twin-wires are mostly used for newsprint production , followed by printing and writing paper in the DMEs and tissue in the DPEs. In the CPEs, twin-wires are mostly used for printing and writing paper production.

By type of twin-wire units, the two dominant units in the DMEs were the Bel Baie, the Duoformer C followed by the Papriformer In the CPEs, it was the Speedformer, the Bel Baie and the Verti-Forma and the Duoformer C. In tissue production, the units adopted were similar- the Periformer dominates in both the developed market and the centrally-planned economies, followed in the case of the developed market economies by Beloit Tissue and the Duoformer T and the Tisco-Former. In the case of the CPEs, it was the Duoformer T which takes up the remaining portion while in the developing market economies it was the Beloit Tissue and the Douformer T which dominated. In addition, while both pure twin-wires and top wires were used in the production of newsprint and printing/writing papers, all units for tissue production were pure twin-wires.

Table 5.6 shows the distribution of twin-wires among the 46 countries that had adopted the technology by 1988. The cumulative frequency graph of the 46 adopter countries is given by Fig. 5.2. The graph shows that the last time there was a new twin-wire adopter country was in 1985. Except for 1981, the graph also indicates that there has been at least one adopter country, each year from 1968 to 1988. Thus approximately 50 per cent of the 46 countries adopted the twin-wire innovation within the first decade of of its introduction. The pattern of adoption was fairly regular during the first decade, with an average of about 3 countries per year except in 1974 and 1975. In contrast, the pattern of country adoption in the second decade was marked by larger numbers of

Table 5.6 **Countries With Twin-Wire Units As of 1988**

Country	Number	Country	Number	Country	Number
Argentina	1	India	5	Poland	1
Australia	7	Indonesia	2	Romania	1
Austria	7	Iran	1	South Africa	7
Belgium	7	Ireland	1	Spain	3
Brazil	7	Italy	8	Sweden	41
Bulgaria	1	Japan	88	Switzerland	5
Canada	104	Jordan	1	Taiwan	2
Chile	3	Korea	3	Thailand	2
China	3	Kuwait	1	Turkey	3
Colombia	1	Malaysia	1	US	122
Czechoslovakia	3	Mexico	13	US.S.R	10
FRG	32	Netherlands	9	UK	19
Finland	30	New Zealand	2	Venezuela	1
France	17	Norway	10	Vietnam	2
Greece	3	Peru	1	Yugoslavia	2
Hungary	1				

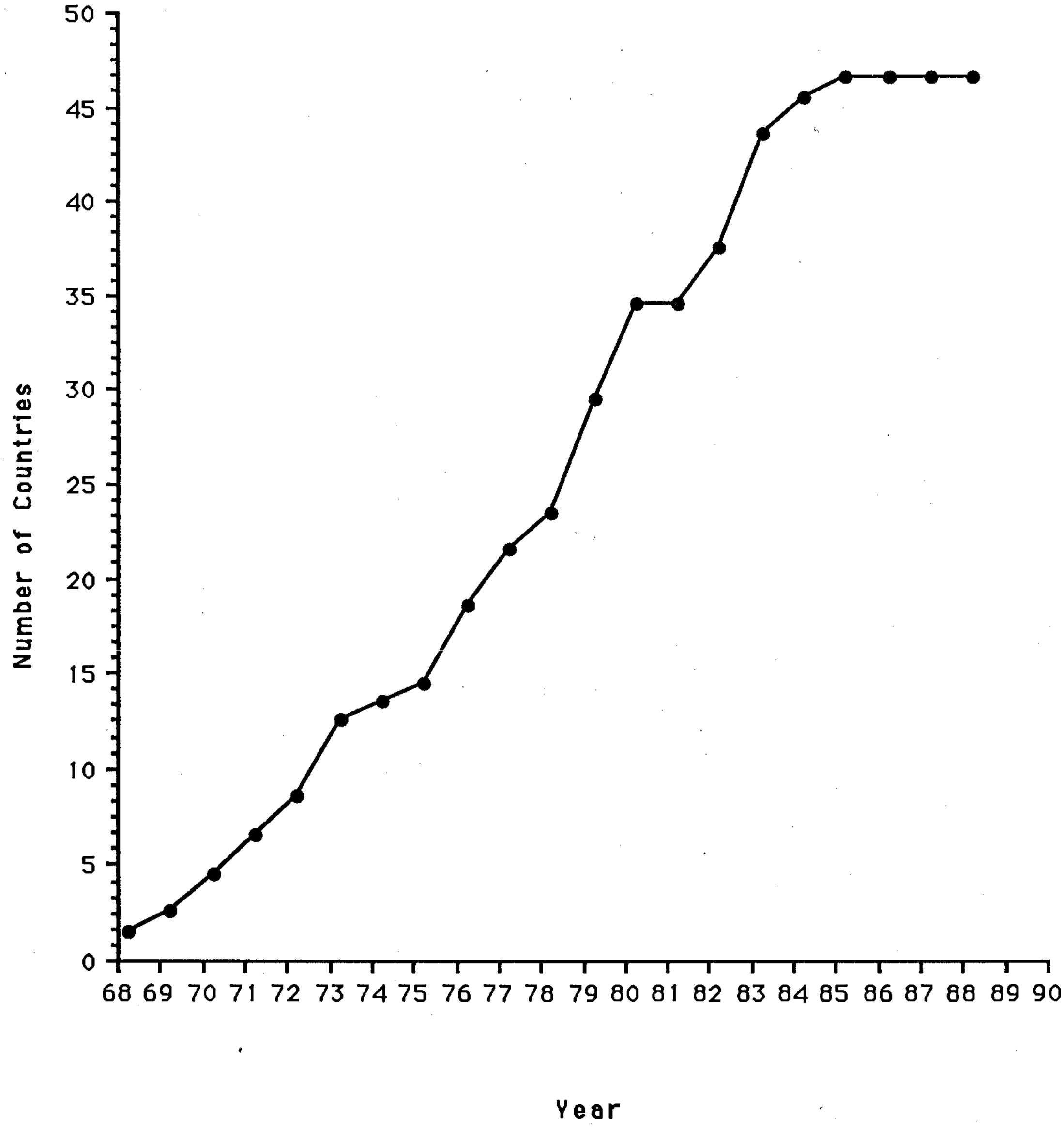
Total Number of Countries: 46. Total Number of Twin-Wires: 594. Also note that this total does not include 10 twin-wires because of incomplete information. Of the 10, 3 were installed in Canada and 2 in Japan. This means the actual total for Canada should be 107 and Japan, 90.

Table 5.7: **Diffusion Lags of Countries With Twin-Wire Units As of 1988**

Country	Lag (Years)	Country	Lag (Years)	Country	Lag (Years)
Canada	0	Netherlands	8	Korea	12
Japan	1	Romania	8	New Zealand	12
UK	2	Switzerland	8	South Africa	12
US	2	FRG	9	Vietnam	12
Finland	3	Greece	9	Hugary	14
France	3	Peru	9	Kuwait	14
Italy	4	Turkey	10	Spain	14
Sweden	4	US.S.R	10	Austria	15
Argentina	5	Australia	11	Czechoslovakia	15
Brazil	5	Chile	11	Jordan	15
Mexico	5	Iran	11	Malaysia	15
Norway	5	Ireland	11	Thailand	15
India	6	Poland	11	Venezuela	15
Yugoslavia	7	Taiwan	11	Bulgaria	16
Belgium	8	Colombia	12	Indonesia	16
				China	17

Total Lag: 435 years　　Mean Diffusion Lag: 9.46 years

FIG. 5.2: TWIN-WIRE ADOPTER COUNTRIES 1968-1988



Source: Installation lists of Twin-Wire Manufacturers and
Pulp and Paper International's Twin-Wire Survey.

adoption in shorter time periods and vice versa. Thus, the largest number of adopter countries occurred at the beginning of the second decade, in 1979 and also in 1983, when there were 6 new country adopters in both periods. Indeed, 50 per cent of the countries which adopted during the second decade did so within the first two years of that period, that is 1979 and 1980. Yet in the last three years of the period only one country adopted.

The diffusion lags for the 46 countries ranges from 1 year to 17 years with the mean diffusion lag of 9.2 years (Table 5.7). On the basis of their broad economic regions, the lag increases from 7.2 years in the DMEs through 11 years in the DMEs to 12 years in the CPEs. The adjusted AFA is 1 in 0.4 years which means that since the twin-wire was introduced in 1968, there was a new adopter-country in every 5 months, on the average. Calculating similar values for four distinctive sub-periods in total diffusion period, we obtain 1 in 5 months, 1 in 4 months, 1 in 3 months and 1 in 12 months for the periods of 1968 to 1973, 1974 to 1978, 1979 to 1984 and 1984 to 1988 respectively. This means that the lag per adopter-country decreased progressively from 1968 to 1984 but increased from 1984 to 1988. Attention is now focussed on the diffusion patterns in the major twin-wire adopter countries, including Canada. Explanations for some of these global patterns, such as the dominance of newsprint and also DMEs in twin-wire adoption, and the low level of twin-wire adoption in 1974 and 1975, are not difficult to find and have been touched upon in previous chapters. However, patterns as to inter-country differences such as between those which adopted within the first decade and after and even between countries which adopted the twin-wire within the same time period are not easy to find. For example, it might appear from the onset that all the countries which adopted the twin-wire during the first decade of the innovation would be from the DME group' those adopting during the second decade would either be from the CPE or DPE group. However, as indicated by Table 5.7, this was not necessarily the case. Both time periods had a mix from all the three groups even though most of the countries adopting during the first decade were from the DMEs. Moreover, some DPE countries such as Brazil, Argentina and Mexico, even had twin-wire installations before such an important paper producer as the Federal Republic of Germany (FRG). In short some of the issues involved in these patterns are are complex enough to warrant a more detailed analysis. Therefore, attention will now focus on the diffusion pattern of the major twin-wire adopter countries, including Canada.

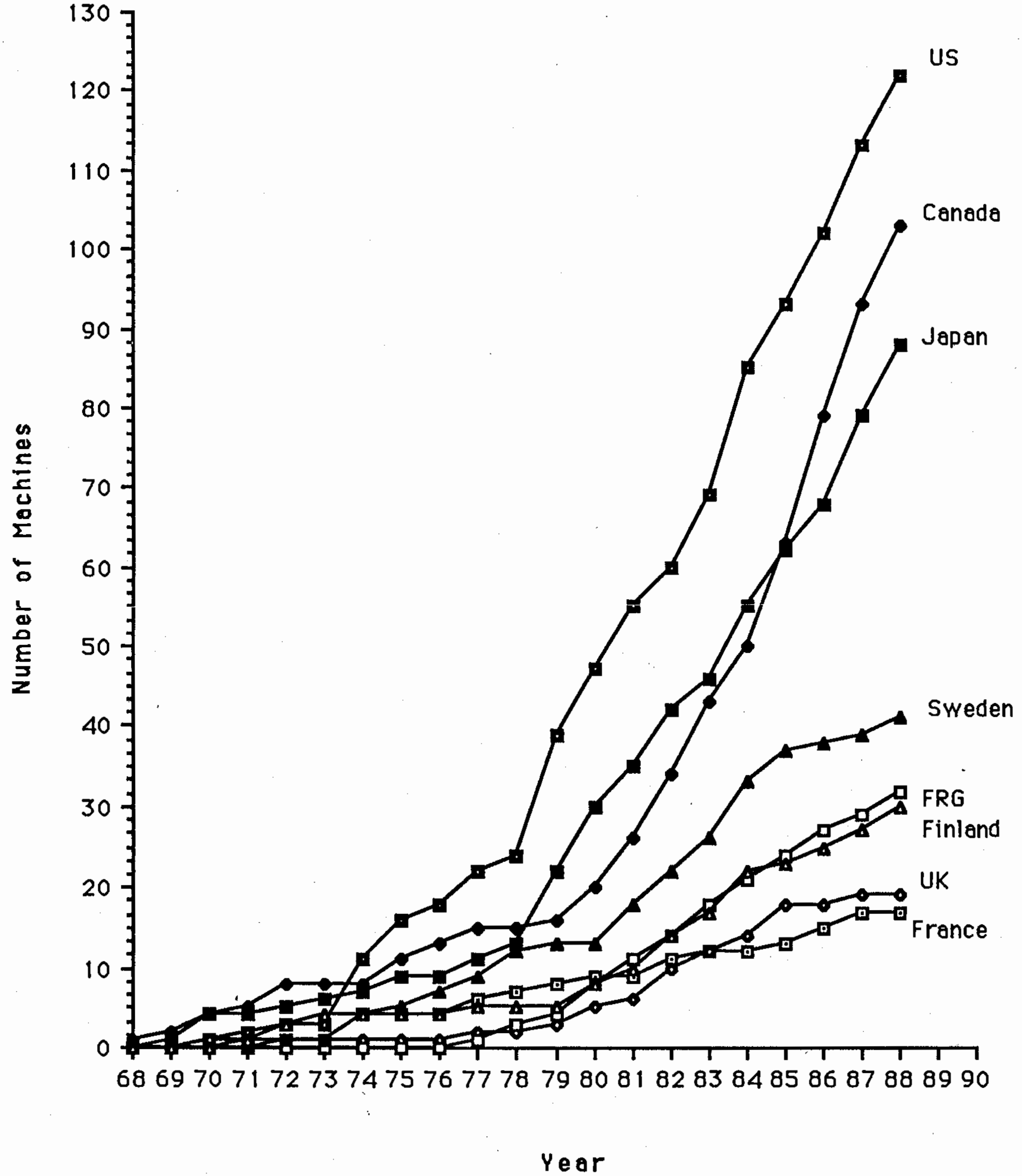
Diffusion Patterns of Major Adopter Countries

As indicated by Table 5.6, the major adopter countries of the twin-wire technology as of 1988 were the US, which had 122 (20 per cent) of all the twin-wire installations from 1968-1988, followed by Canada 104 (17 per cent), Japan 88 (15 per cent), Sweden 41 (7 per cent), FRG 32 (6 per cent), Finland 30 (5 per cent), UK 19 (3 per cent) and France 17 (3 per cent). Together, these 8 countries accounted for about 76 per cent of the world's twin-wire installations as of 1988. The cumulative frequency graph of twin-wire installations in each of these countries is given by Fig 5.3. First, the dominance of the US is clearly established. Second, the countries fall into two main groups. In the first group are the US, Canada and Japan. In the second, are the European countries of Sweden, FRG, Finland, France and UK. Countries in the first adopted earlier than countries in the second group. The number of twin-wires possessed by the leading twin-wire country in the second group, Sweden, was less than half the number of twin-wires possessed by the least twin-wire country in the first group, Japan. Together, the countries in the first group had about 53 per cent of all the twin-wires in the world, while the countries in the second group accounted for 23 per cent. Irrespective of group, the number of twin-wires adopted by each country during the first decade of the innovation was far less than half of the total number of adoptions just like the global pattern. With the exception of France, which had 37 per cent of its total machines adopted within the first decade, all the rest had less than 30 per cent of their adoption within the first decade.

Differences in first twin-wire adoptions can also be observed. Canada innovated the twin-wire in 1968. Japan followed in 1969. The US and the UK followed in 1970, Finland in 1971, Sweden and France in 1972 and FRG in 1977. The lag between FRG and the rest of the countries is significant. After installation of the first machines adoption rates varied among countries. Thus,

FIG. 5.3: TWIN-WIRE INSTALLATIONS IN SELECTED COUNTRIES

1968-1988



Source: Installation lists of Twin-Wire Manufacturers and
Pulp and Paper International's Twin-Wire Survey

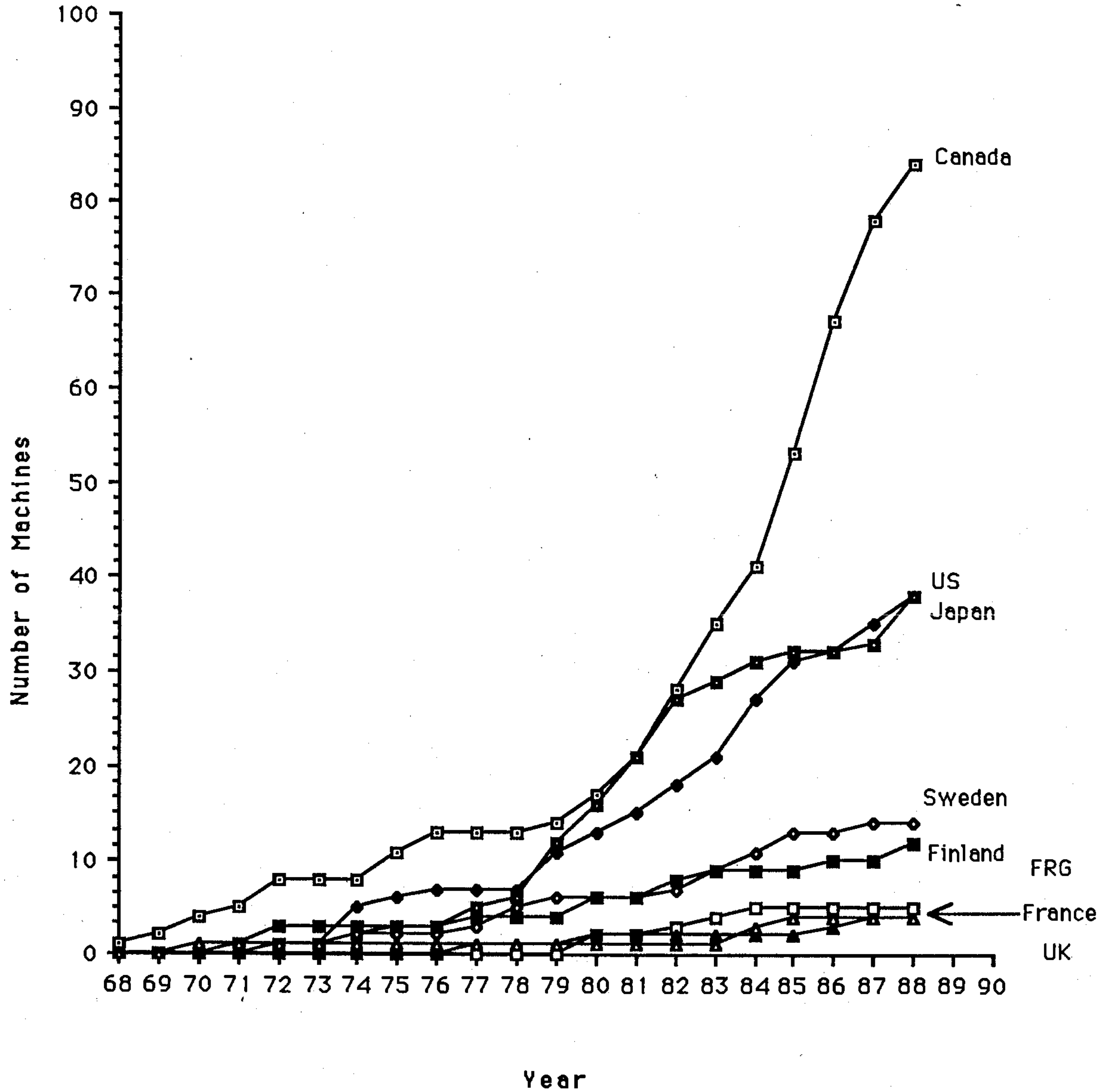
by the end of the first decade, the US had established a comfortable lead in terms of number of twin-wire adoptions. Canada and Japan were almost tied in the second second position, followed by Sweden, France, Finland, UK and FRG. By the end of the second decade, the US was still leading in the number of twin-wires; Canada was in the second position followed by Japan, Sweden, FRG, Finland, UK and then France. Another adoption pattern that can be observed is the significant spurts of adoption that occurred at certain time periods. Thus in the US, this included 1979 and 1982. In Canada, significant adoption spurts occurred in 1982 to 1987. In Sweden it was 1980 and 1983. Finally, another feature about the twin-wire adoptions in the European countries as given by the graph is the closeness between the number of twin-wire adoptions in the FRG and Finland, particularly since 1979.

Further insights into these adoption patterns can be obtained from the product perspective even as indicated by Figs 5.4 and 5.5. Thus Canada's position as the innovator of the twin-wire technology and also as the world's second twin-wire adopter-nation is almost exclusively in newsprint (Fig 5.4). In addition, with respect to newsprint machines, the US and Japan shared comparable experience, as did Finland and Sweden, and FRG, France and UK (Fig 5.4). With respect to printing and writing paper, however, patterns varied (Fig 5.5). Between 1968 and 1978, the most important adopter country was France. From 1979 to 1988, Japan and the US became the dominant countries. The two countries shared comparable experiences during the 1979-1988 period, with the US dominating particularly from 1981 to 1987. In addition, significant adoption spurts occurred in 1979, 1983 and 1985. In Japan, most of the adoptions occurred in 1984, 1985, 1986 and 1987. Finland and FRG also shared comparable experiences during that period. Canada was a late comer in the adoption the twin-wire for the production of printing and writing paper.

Thus the product characteristics of the twin-wire adopted were different. While the overwhelming majority of twin-wires adopted in Canada (96 per cent) were devoted to newsprint

FIG. 5.4: TWIN-WIRE NEWSPRINT MACHINES 1968-1988

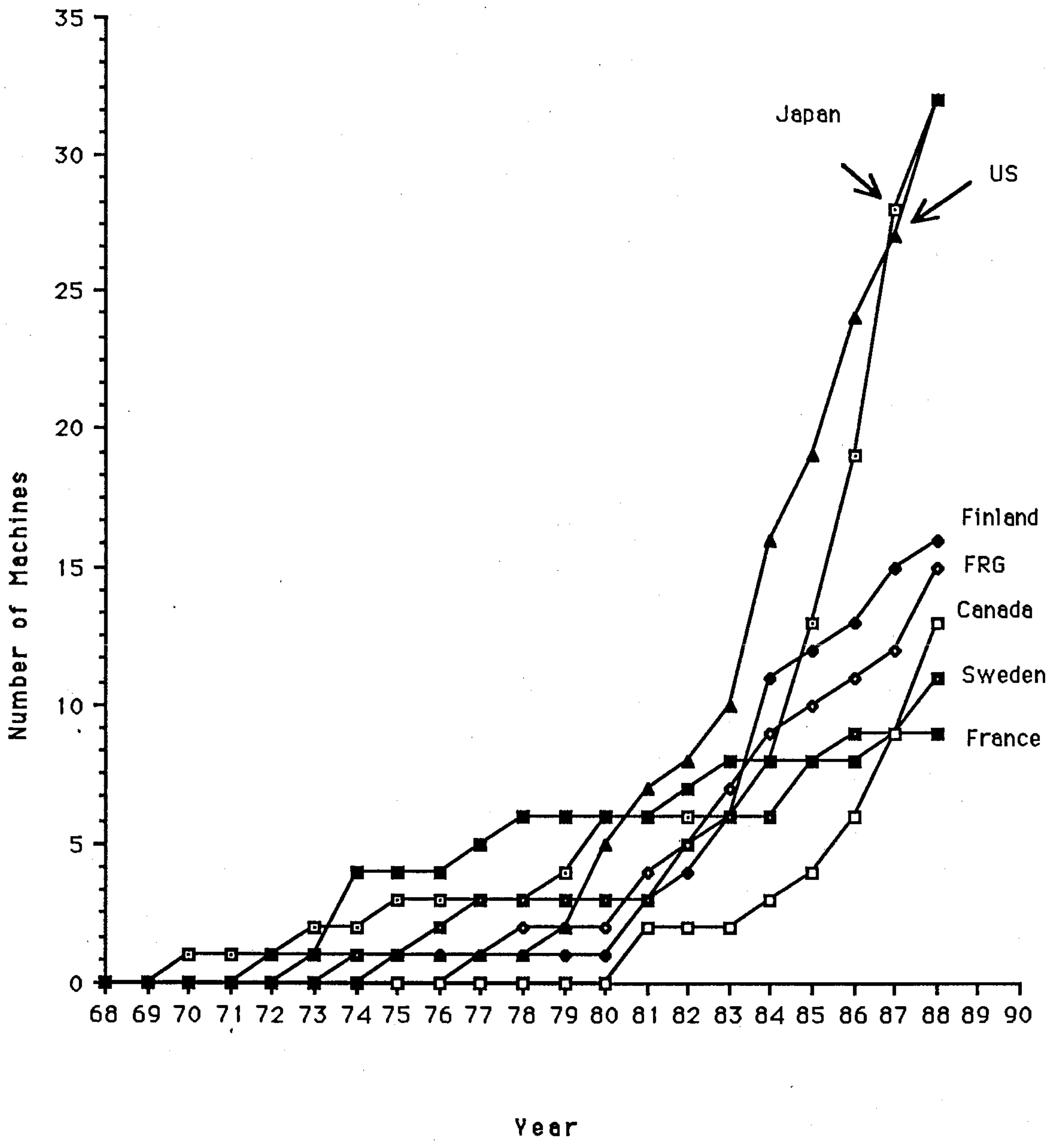
(SELECTED COUNTRIES)



Source: Installation lists of Twin-Wire Manufacturers and
Pulp and Paper International's Twin-Wire Survey.

FIG. 5.5: TWIN-WIRES FOR PRINT/WRIT PAPER 1968-1988

(SELECTED COUNTRIES)



Source: Installation lists of Twin-Wire Manufacturers and
Pulp and Paper International's Twin-Wire Survey.

production, in the US and in Japan the distribution of twin-wires for the production of the various grades was fairly even. In the US, 31 per cent of machines adopted were devoted to newsprint production, 28 per cent to tissue, 26 per cent to printing and writing paper and 15 per cent to the remaining grades. In Japan it was 44 per cent to newsprint production, 36 per cent to printing and writing paper, and 17 per cent in other paper and board. The distribution of twin-wires adopted in Sweden also shows a similar trend: 34 per cent was devoted to newsprint, 27 per cent to printing and writing paper and 27 per cent to other paper and board. In contrast, both Finland and FRG had most of their twin-wire machines devoted to the production of printing and writing paper: 53 per cent in Finland and 47 per cent in the FRG with tissue accounting for 33 per cent and 22 per cent in the two countries, repectively (Table 5.8).

By category of machine, pure twin-wires dominated the scene until 1979 when top wires began to be installed. By 1988, there were more top wires in all the countries, than pure twin-wires. In Canada pure twin-wires accounted for 35 per cent of the total number of adoptions by 1988. In the US, it was 47 per cent, in Japan, 42 per cent and in Sweden, 41 per cent while for Finland and FRG, it was 16 per cent and 18 per cent respectively (Table 5.9). This means that Canada, US, Japan and Sweden showed a fairly higher proportion of pure twin-wires compared to FRG and Finland. Differences also exist in the timing of top wire adoptions. For Canada, Japan and the US, it was not until after 1979 while the European countries adopted it earlier, with Finland adopting its first top wire in 1973, Sweden in 1976 and the FRG in 1977. In spite of these differences in the timing of adoptions, top wires really became important in all the countries only after 1980 (Table 5.9). As a result of these differences in concentration of pure and hybrid twin-wires, the category of machines that were used for the production of various grades over the period also differed. With the exception of Japan and Sweden, all the countries including Canada, had more top wires in newsprint production (Table 5.10). In printing and writing paper, Canada, US and Japan had a relatively few numbers of top wires, while European countries had mostly top twin-wires. In Finland and the FRG, there were no pure twin-wires in this sector. The same applies to the other paper and

Table 5.8 **Product Characteristics of Twin-Wires In The Major Twin-Wire Adopter Countries, 1968-1988**

Country	Newsprint	Print/Writ Pap	Tissue	Other Paper	Total
Canada	85	14	4	-	103 †
FRG	5	15	7	5	32
Finland	12	16	1	1	30
France	4	7	4	-	15
Japan	39	32	2	15	88
Sweden	14	11	5	11	41
UK	4	2	6	7	19
US	38	32	34	19	122
Total	201	129	63	58	451

Source: PPI Twin-Wire Survey, 1984 and Installation lists of Twin-Wire Manufacturers
†1 unit could not be classified

Table 5.9: **Twin-Wires By Machine Category In The Major Twin-Wire Adopter Countries, 1968-1988**

	Canada		US.		Japan		Finland		Sweden		FRG		France		UK	
	PTW	TW	PTW	TW	PTW	TW	PTW	TW	PTW	TW	PTW	TW	PTW	TW	PTW	TW†
1968	1	-	-	-	-	-	-		-	-	-	-	-	-	-	
1969	1	-	-	-	1	-	-		-	-	-	-	-	-	-	
1970	2	-	1	-	3	-	-		-	-	-	-	-	-	1	
1971	1	-	1	-	-	-	1		-	-	-	-	-	-	-	
1972	3	-	1	-	1	-	2		1	-	-	-	1	-	-	
1973	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	
1974	-	-	8	-	1	-	-		4	-	-	-	3	-	-	
1975	3	-	5	-	2	-	-		1	-	-	-	-	-	-	
1976	2	-	2	-	-	-	-		1	1	-	-	-	-	-	
1977	2	-	4	-	2	-	-	1	2	-	-	1	2	-	-	1
1978	-	-	2	-	2	-	-		2	1	1	1	1	-	-	
1979	1	-	9	6	8	1	-		1	-	1	-	1	-	1	
1980	1	2	7	1	5	3	1	2	-	-	1	3	1	-	-	2
1981	6	1	5	3	2	3	-	2	1	-	-	3	-	-	1	
1982	5	3	1	4	3	4	-	4	1	6	1	2	1	1	1	3
1983	4	5	1	8	-	4	-	3	1	3	1	3	-	1	2	
1984	-	7	3	13	1	8	-	5	2	5	-	3	-	-	-	2
1985	2	11	1	7	1	6	-	1	1	3	-	3	1	-	-	4
1986	1	15	1	8	-	6	-	2	-	1	2	1	1	1	-	
1987	2	12	3	8	1	10	-	2	1	-	-	2	-	2	-	1
1988	-	10	3	6	3	6	1	2	-	2	-	3	-	-	-	
Total	37	66	58	64	37	51	5	25	18	23	7	25	12	5	6	13

†PTW = Pure Twin-Wire; TW = Top Wire

Table 5.10 **Product Characteristics By Twin-Wire Category In The Major Twin-Wire Adopter Countries, 1968-1988**

	Newsprint		Printing/Writing		Tissue		Other Paper		
	P. Twin-Wire	Top Wire	P Twin-Wire	Top Wire	P Twin-Wire	Top Wire	P Twin-Wire	Top Wire	Total
Canada	29	56	4	10	4		-	-	103 †
FRG	-	5	-	15	7		-	5	32
Finland	4	8	-	16	1		-	1	30
France	2	2	5	2	4		-	-	15
Japan	27	12	4	28	2		4	11	88††
Sweden	10	4	2	9	5	-	1	10	41
UK	1	3	-	2	6		-	7	19
US	16	22	4	28	34		4	15	122
Total	89	112	19	108	58	5	9	49	449

Source: PPI Twin-Wire Survey, 1984 and Twin-Wire Installation lists of Twin-Wire Manu facturers.
P. Twin-Wire = Pure twin-wire
†1 unit could not be added due to incomplete information.
†† 2 units could not be added due to incomplete information

board grades. In tissue, however, all the machines in all the countries were pure twin-wires.

Finally, differences can be observed in the type units of machines adopted. The Bel Baie family of machines dominated the number of pure twin-wire adoptions in Canada, the US, Japan and in Sweden. In Sweden, the Periformer was important. Among the top wires, however, there were differences in the dominant machine unit. In Canada, it was the Top Flyte, followed by the Symformer family. In the US, it was the Bel Bond, followed by the Symformer. In Japan, it was the Duoformer family, followed by the Bel Bond. In Sweden and Finland, it was the Symformer followed in Sweden by the Bel Bond while in the FRG, it was the Duoformer (Table 5.11). Table 5.12 also shows some information on how forest product firms in the major forest product nations have contributed to these patterns. In particular, it can be seen that North American firms and particularly Canadian firms have the largest number of installations. The only firms that come closer to the Canadian firms are Taio and Daishowa Papers of Japan and Enso Gutzeit of Finland. In fact it is the largest newsprint makers which have the largest number of twin-wire installations.

These diffusion patterns reflect individual firm behaviour which in turn reflects on the differences in resource inputs, market locations, production specialisations and industry structure of the countries in which the firms are located. As indicated in Chapter 3, the unit cost of production of a ton of newsprint decreases with increasing output. The immense capacity of the twin-wire over the fourdrinier in terms of its speed and quality makes the twin-wire much more suitable for the production of newsprint. Hence most of the twin-wires are in newsprint production. However, the large component of wood in newsprint production makes newsprint production economical only in regions with cheap sources of wood. The relative abundance of accessible wood sources in North America, has historically given North America a production cost advantage over other pulp and paper producing regions particularly in the production of bulk products. Thus, historically, Canada's traditional strength in the paper industry has been in the newsprint sector. Canadian pulp and paper firms are the world's biggest newsprint producers. In contrast, the dwindling wood resources in Europe and Japan during the 1960s, which was mentioned in Chapter 3, made it

Table 5.11: **Different Types of Twin-Wire Units In Major Twin-Wire Adopter Countries As of 1988**

	Canada		US		Japan		Finland		Sweden		FRG		France		UK	
Category/Type	68-78	79-88	66-78	79-88	68-78	79-88	68-78	79-88	68-78	79-88	68-78	79-88	68-78	79-88	68-78	79-88
Pure Twin-Wires																
Bel-Baie	2	-	-	-	-	-	3	-	-	-	-	-	-	-	-	
Bel-Baie II	1	9	6	9	5	16	-	-	3	-	-	-	2	1	-	
Bel-Baie III	-	4	-	1	-	5	-	-	-	3	-	-	-	-	-	
Beloit Tissue	1	-	2	16	1	2	-	-	1	-	1	-	-	2	-	2
ErWePa	-	1	1	-	-	-		-	-	-	-	-	-	-	-	
Duoformer C	-	-	-	1	-	-	-	-	1	1	-	-	-	-	-	-
Duoformer E	-	-	-	-	2		-	-	1	-	-	-	1	-	-	
Douformer T	-	-	1	-	-		-	-	-	-	4	-	-	-	-	
OverformerT	-	-	-	-	-		-	-	-	-	-	-	-	1	-	
Papriformer	6	2	4	-	-	1	-	-	-	-	-	-	3	-	-	
Periformer LW	1	2	5	3	-		-	-	1	3	-	1	-	-	-	3
Periformer MW	-	1	3	3	-		-	-	2	-	-	-	-	-	-	
Speed Former T	-	-	-	-	-	-		-	-	1	-	-	-	-	-	
Speed Former HS	-	-	-	1	-	-		1	-	-	-	-	-	-	-	
Tisco Former	-	-	-	-	-	-		-	-	-	-	-	-	1	-	
Verti-Forma I	3	-	2	-	-		-	-	-	-	-	-	-	-	1	
Verti-Forma J	1	-	1	-	5	1	-	-	1	-	-	-	1	-	-	
Verti-Forma V	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	
Total	15	22	24	34	13	25	3	1	10	8	5	1	6	5	2	5
Top Wires																
Bel Bond	-	5	-	24	-	13	-	2	1	9	-	1	-	1	1	6
Bel Form	-	9	-	9	-	3		3	-	-	-	-	-	-	-	
Bel Roll	-	2	-	6	-	1	-	-	-	-	-	-	-	-	-	
Duoformer D	-	-	-	-	-		-	-	-	-	-	5	-	-	-	1
Duoformer F	-	1	-	4	-	14	-	-	-	1	1	7	-	1	-	1
Duoformer FM	-	-		-	-	1	-	-	-	-	-	-	-	-	-	
Duoformer H	-	-	-	4	-	4	-	-	-	-	-	5	-	-	-	
Duoformer K	-	-	-	1	-	3	-	-	-	-	-	2	-	-	-	
Dynaformer†	-	2	-	1	-	1	-	-	-	-	-	-	-		-	2
H. Bel Baie	-	4	-	-	-		-	-	-	-	-	-	-	-	-	
Sym Former	-	4	-	4	-	2	-	7	-	3	-	-	-	2	-	1
Sym Former F	-	2	-	4	-	1	1	4	1	1	1	1	-	-	-	
Sym Former N	-	3	-	-	-		1	2	-	-	-	-	-	-	-	
Sym Former R	-	6	-	4	-	8	-	7	-	5	-	-	-	1	-	
Sym Former FR	-	5	-	-	-		-	-	-	-	-	-	-	-	-	
Sym Former SF	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	
Top Flyte	-	23	-	1	-	-	-		-	1	-	-	-	-	-	1
TwinFormer L	-	-	-	1	-	-	-		-	-	-	-	-	-	-	
Total		56		63		51	2	25	2	20	2	21		5		12

Table 5.12: **Twin-Wire Installations of Firms In The Major Adopter Countries, 1968-1988**

Country/Firm	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	Total
Canada																						
Abitibi-Price	-	-	-	-		-	-	-	-	-	-	-		1	1	1	3	1	3	5	3	18
Atlantic Packaging	-	-	-	-		-	-	-	-	-	-	-		-	-	1	-	-	-	-	-	1
Boise Cascade	-	-	-	-		-	-	1		-	-	-		-	-	-	-	3	-	-		4
Bowater-Mersey	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	2	-	-	-	2
CP Forest Prod	1	-	2	-		-	-	-	-	1	-	-	1	2	2	-	1	-	2	-	1	13
Consolidated-Barthurst	-	-	-	-	2	-	-	2	-	-	-	1	-	1	2	1	-	-	3	-	2	13
Domtar	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	3		3	-	6
Donohue	-	-	-	-	-		-	-	-	-	-	-	-		1	-	1	-	-	-	-	2
Eddy Forest Prod.	-	-	-	-		-	-	-	1	-	-	-		-	-	-	-	-	-	-	-	1
Fletcher Challenge	-	-	-	-		-	-	-	-	-	-	-		-	2	-	-	-	1	2		5
Kimberly Clark	-	-	-	-		-	-	-	-	-	-	-		-	-	-	-	-	2	1	-	3
Kruger Inc	-	-	-	-	1		-	1	-	-	-	-		2	-	-	2	-2	2	-	1	10
MacMillan Bloedel	-	-	1	-		-	-	-	-	-	-	-	1	1	-	-	-	-	-		1	4
James Maclarent	-	-	-	-		-	-	-	-	-	-	-		-	-	-	-	1	-	-		1
Miramichi	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-		1	-	-	1
Quebec-Ont Paper	-	1	-	1		-	-	-	-	-	-	-		-	2	-	-	-	2	-	1	7
Reed Paper	-	-	-	-		-	-	-	-	-	-	-	-	-	1	1	1	1	-		-	4
Rothesay	-	-	-	-		-	-	-	-	-	-	-		-	-	1	1	-	-	-		2
Scott Paper	-	-	-	-		-	-	-	-	-	-	-		-	-	1	-	-	-	-		1
F.F Soucy	-	-	-	-	-		-	-	1	-	-	-		-	-	1	-	-	-	-	1	3
Stora Indust.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	1	-	1
Weyerhauser	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-		1	1
Total	1	1	3	1	3	-	-	4	2	1	-	1	2	6	11	7	9	13	16	11	12	104
US																						
Augusta Pap	-	-	-	-	-	-		-	-	-	1	-	-	1	-	-		-	-	-	-	2
Bear Is.	-	-	-	-	-	-	-	-		-	-	1	-	-	-	1	-		-	-	-	1
Boise Cascade	-	-	-	-	-	-	-		-	-	-	-	2	-	-	-	1	1	-	-	1	5
Bowater	-	-	-	-	-	-	-		-	-	-	1	-	-	-	1	2	1	-	-	1	6
Champion Intn'l	-	-	-	-	-	-	1	1		-	-	-	-	-	-	-	-		2	-	-	4
Chesapeake	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	1		-	-	-	1
Consolidated Pap	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	1	-	-	1	2
Diamond Intn'l	-	-	-	-	-	-	-	-		-	-	1	-	-	-	-	-		-	-	-	1
FSC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-		-	-	-	1
Fletcher Pap.	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	1		-	-	-	1
Fort Howard	-	-	-	-	-	-	1	1	-	1	1	1	-	1	-	-	2	-	-	-	-	8
Garden State	-	-	-	-	-	-	2		-	-	-	-		1	-	-	-	1	-	-	-	4
Georgia Kraft	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-		1	-	-	1

Continued on the next page

Table 5.12: **Twin-Wire Installations of Firms In Major Adopter Countries, 1968-1988***(Continuation)*

Country/Firm	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	Total
US																						
Georgia Pacific	-	-	-	-	-	-	-		-	2	-	1		1	-	-	-	1	-	1	1	7
Gt. Northern	-	-	-	-	1	-	-		-	-	-	1		-	-	-	-	-	-	1	1	4
Inland Emp	-	-	-	-	-	-	-		-	-	-	-		-	1	-	-	-	-	-	-	1
International Pap	-	-	-	-	-	-	1		-	-	-	-		-	-	2	1	-	2	-	-	6
James River	-	-	-	-	-	-	1		-	-	-	-		-	-	1	1	-	2	1	2	8
Kimberly Clark	-	-	-	-	-	-	-		-	-	-	-		-	-	-	-	-	1	-	-	1
Lake Superior	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	1	-	1
Madison Pap	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-		-	-	1	1
Manistique	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	1	-	-	-	1
Marcal	-	-	-	-	-	-	-		-	-	1	-	-	-	-	-		-	-	-	-	1
Mead Corp	-	-	-	-	-	-	-		-	-	-	-	-	1	-	-	-	1	-	-	-	2
Mid-Tech Pap	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-		-	-	1	1
N. Pacific	-	-	-	-	-	-	-	-		-	-	1	-	1	-	-	-		-	-	-	2
Olinkraft	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	1
Owen-Illinois	-	-	-	-	-	-	-		-	-	-	1	-	-	-	-	-		-	-	-	1
Potlatch	-	-	-	-	-	-	-		-	-	-	-	1	-	-	-		-	-	-	-	1
Proct & Gamb	-	-	-	-	-	-	-		-	-	-	-	1	-	-	-	-	-	-	-	-	1
St Regis	-	-	-	-	-	-	1		1	-	-	5		-	-	-	-	-	-	-	-	7
Scott Paper	-	-	-	-	-	-	-		-	-	-	-		1	-	-	-	-	-	-	-	1
Smurfit	-	-	-	-	-	-	-		-	-	-	-	1	-	-	1	2	-	-	1	1	6
S.E Paper	-	-	-	-	-	-	-		-	-	-	1		-	-	-	-	-	-	-	-	1
S.W Forest	-	-	-	-	-	-	-	1	-	-	-	-		1	-	-	-	-	-	-	-	2
Union Camp	-	-	-	-	-	-	-		-	-	-	-		-	-	-	1	-	-	-	-	1
S.D Warren	-	-	-	-	-	-	-		-	-	-	-		-	1	-	-	-	1	1	-	3
Westvaco	-	-	-	-	-	-	-		-	-	-	-		-	-	1	2	-	-	-	-	3
Weyerhauser	-	-	1	-	-	1	-	1	-	-	-	1		-	-	-	-	-	-	-	-	4
Western Kraft	-	-	-	-	-	-	-		-	-	-	-		1	-	-	-	-	-	-	-	1
Willamette	-	-	-	-	-	-	-		-	-	-	-		-	-	2	-	-	-	2	-	4
Wisconsin Tiss	-	-	-	-	-	-	-		-	-	-	-		-	1	-	-	-	-	-	-	1
Undisclosed	-	-	-	-	-	-	2	1	-	1	1	1	1	-	-	-	1	1	-	2	-	11
Total	-	-	1	1	1	1	9	5	1	4	4	16	6	9	3	9	15	8	9	10	10	122
Japan																						
Daishowa Paper	-	1	-	-	-	1	1	1	-	-	-	-	-	1	-	1	-	1	1	5	-	13
Chuo Paper	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	2		-	-	-	2
Chuetsu Pap	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-		-	1	-	1	2
Honshu Paper	-	-	1	-	-	-	-		-	-	-	-	-	1	-	-	2	1	1	1	-	7
Hokuetsu Paper	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	1	1	-	-	2

Continued on the next page

Table 5.12: **Twin-Wire Installations of Firms In Major Adopter Countries, 1968-1988***(Continuation)*

Country/Firm	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	Total
Japan																						
Hyogo Pap	-	-	-	-	-	-	-	-		-	-	-	-	-	1	1	-		-	-	-	2
Jujo Paper	-	-	-	-	1	-	-	-	-	1	-	2	1	1	-	-	-	1	1	1	-	9
Kanzaki	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	1		-	-	-	1
Kitagami	-	-	-	-	-	-	-		-	-	-	-	-	1	-	-		-	-	-	-	1
Marusumi	-	-	-	-	-	-	-		-	-	-	1		-	-	-	1	-	1	1	1	5
Mitsubishi Pap	-	-	-	-	-	-	-	1	-	-	-	-		-	-	-	-	1	-	-	1	3
Ohtake Paper	-	-	-	-	-	-	-		-	-	-	-	1	-	-	-	-	-	-	-	-	1
Oji Paper	-	-	-	-	-	-	-		-	-	2	1	1	1	2	-	-	1	1	-	1	9
Osaka Paper	-	-	-	-	-	-	-		-	-	-	-		-	1	-	-	-	-	-	-	1
Sanko	-	-	1	-	-	-	-		-	-	-	-		-	-	-	-	-	-	-	-	1
Sanyo	-	-	-	-	-	-	-		-	-	-	-		-	2	-	-	-	-	1	-	3
Sanyo Scott	-	-	-	-	-	-	-		-	-	-	1		-	-	-	-	-	-	-	-	1
Settsu Paper	-	-	-	-	-	-	-		-	-	-	1		-	-	-	1	-	-	1	-	3
J.N. Project	-	-	-	-	-	-	-		-	-	-	-		-	-	-	-	-	-	-	1	1
Taio Paper	-	-	-	-	-	-	-		-	1	-	1	1	-	1	2	2	1	-	1	4	14
Tonami	-	-	-	-	-	-	-		-	-	-	-	1	-	-	-	-	-	-	-	-	1
Toyo	-	-	1	-	-	-	-		-	-	-	-		-	-	-	-	-	-	-	-	1
Tsurusaki	-	-	-	-	-	-	-		-	-	-	-	1	-	-	-	-	-	-	-	-	1
Total	-	1	3	-	1	1	1	2	-	2	2	7	6	5	7	4	9	7	7	11	9	85*
Finland																						
Enso Gutzeit	-	-	-	1	1	-		-	-	-	-	-	1	-	3	-	-	1	-	1	1	10
Kajaani	-	-	-	-	-	-	-	-		-	-	-	-	-	1	-	-		-	-	1	2
Kyimi Kymmene	-	-	-	-	-	-	-		-	-	-	-	-	-	1	1		1	-	-	1	4
Metsa-Sevla	-	-	-	-	-	-			-	-	-	-	-	1	-	-	-		-	-	-	1
Nokia	-	-	-	-	-	-	-	-		-	-	-	1	-	-	-	-		-	-	-	1
Kyro Oy	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	1		-	-	-	1
Rauma-Repola	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1		-	-	-	2
Tampella	-	-	-	-	-	-	-		-	-	-	-	-	-	-	1	-		-	-	-	1
Veitsiluoto	-	-	-	-	1	-	-		-	-	-	-	-	-	-	-	2	-	-	-	-	3
United Paper	-	-	-	-	-	1	-		-	-	-	-		1	-	1	-	-	1	1	-	5
Total	-	-	-	1	2	1	-	-	-	1	-	-	3	2	5	3	4	2	1	2	3	30

Continued on the next page

Table 5.12: **Twin-Wire Installations of Firms In Major Adopter Countries, 1968-1988**(*Continuation*)

Country/Firm	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	Total
Sweden																						
Billeruds	-	-	-	-	-	-		-	-	-	1	-	-	4	-	-	-	-	-	-	-	5
Duni Bila	-	-	-	-	-	-	-	-		-	-	-	-	-	-	1	-		-	-	-	1
Edet	-	-	-	-	-	-	-		-	-	-	-	-	1	-	-		-	-	-	-	1
Fiskeby	-	-	-	-	-	-	1		-	-	-	-	-	-	1	-	-		-	-	-	2
Holmens Bruk	-	-	-	-	1	-	1	-		1	-	-	-	-	1	-	1		1	-	-	6
Hylte Bruk	-	-	-	-	-	-	-	-		-	-	1	-	-	-	1	-	1	-	-	-	3
Iggesund Bruk	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5		-	-	-	5
Klippans	-	-	-	-	-	-	1		-	-	-	-	-	-	-	-	-		-	-	-	1
Lilla	-	-	-	-	-	-	-		1	-	-	-	-	-	-	-		-	-	-	-	1
MoDo Paper	-	-	-	-	-	-	-		1	-	-	-		1	1	-	-	1	-	-	-	4
Munkedals	-	-	-	-	-	-	-		-	1	-	-		-	-	-	-	-	-	-	-	1
Nymolla	-	-	-	-	-	-	-		-	-	-	-		-	-	-	-	1	-	-	1	2
Obbola Liner	-	-	-	-	-	-	-	1	-	-	-	-		-	-	-	-	-	-	-	-	1
Stora Kopp.	-	-	-	-	-	-	-		-	-	1	-		-	-	-	-	-	-	1	1	3
Svenska Cel.	-	-	-	-	-	-	-		-	-	1	-		-	1	-	1	1	-	-	-	4
Wifstavarfs	-	-	-	-	-	-	-		-	-	-	-		-	1	-	-	-	-	-	-	1
Total	-	-	-	-	1	-	3	1	2	2	3	1		6	5	2	7	4	1	1	2	41
FRG																						
Feldmuhle	-	-	-	-	-	-		-	-	-	-	1	1	-	-	-	-	-	1	-	-	3
Gebr.Lang	-	-	-	-	-	-	-	-		-	-	-	-	-	-	1	-		-	-	-	1
Haindl Papier	-	-	-	-	-	-	-		-	-	1	-	1	-	1	1		1	-	-	-	5
Hakle	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-		1	-	-	1
Hannoversche	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	1		-	-	-	1
C.D Haut	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	1	-	-	-	1
OLW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1
E. Hotzmann	-	-	-	-	-	-	-		-	-	-	-	1	-	-	-	1		-	1	-	3
Koehler	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-			-	1	-	1
MD Papiefab	-	-	-	-	-	-	-		-	-	-	-		-	-	-	-	-	-	-	1	1
Norland Papier	-	-	-	-	-	-	-		-	1	-	-		-	1	-	-	1	-	-	-	3
Papier Fabric	-	-	-	-	-	-	-		-	-	-	-		1	-	-	-	-	-	-	-	1
PWA	-	-	-	-	-	-	-		-	-	-	-	1	1	2	-	-	-	1	-	-	5
Schickendanz	-	-	-	-	-	-	-		-	-	1	-		-	-	-	-	-	-	-	-	1
Steinbei	-	-	-	-	-	-	-		-	-	-	-		-	-	1	-	-	-	-	-	1
Zanders	-	-	-	-	-	-	-		-	-	-	-		-	-	-	-	-	-	-	2	2
Undisclosed	-	-	-	-	-	-	-		-	-	-	-		-	-	1	-	-	-	-	-	1
Total	-	-	-	-	-	-	-		-	1	2	1	4	2	4	4	2	4	3	2	3	32

Continued on the next page

Table 5.12: **Twin-Wire Installations of Firms In Major Adopter Countries, 1968-1988***(Conclusion)*

Country/Firm	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	Total
France																						
Arjomari Prioux	-	-	-	-	1	-		-	-	-	-	-	-	-	3	-	-	-	-	-	-	1
Aussedat	-	-	-	-	-	-	1	-		-	-	-	-	-	-	-	-		-	-	-	1
Beghin Say	-	-	-	-	-	-	-		-	-	-	-	-	-	1	-		-	-	-	-	1
Bourray	-	-	-	-	-	-	-		-	-	1	1	-	-	-	-	-	1	-	-	-	3
Boussac St.Freres	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-		-	-	1	1
Chapelle-Dar	-	-	-	-	-	-	-	-		-	-	-	1	-	-	-	-		-	-	-	1
Clairefontanie	-	-	-	-	-	-	1		-	-	-	-		-	-	-	-	-	-	-	-	1
Ledar Pap	-	-	-	-	-	-	-		-	1	-	-	-	-	-	-		-	-	-	-	1
Mougeot	-	-	-	-	-	-	-	-		-	-	-	-	-	-	1	-		-	-	-	1
Moulin	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-		-	-	-	1
Papier de Pont	-	-	-	-	-	-	-		-	-	-	-		-	1	-	-	-	1	-	-	1
Remap	-	-	-	-	-	-	-		-	-	-	-		-	-	-	-	-	1	2	-	3
Ruysscher Pap	-	-	-	-	-	1	-		-	-	-	-		-	-	-	-	-	-	-	-	1
Total	-	-	-	-	1	-	3		-	2	1	1	1	-	5	1	-	1	2	2	1	17
UK																						
Bowater	-	-	1	-	1	-		-	-	-	-	-	-	-	3	-	-	1	-	-	-	2
British Tissue	-	-	-	-	-	-	-	-		-	-	-	-	-	-	2	-		-	-	-	2
Consolidated-Bathurst	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	2	-	-	-	-	2
C. Davidson	-	-	-	-	-	-	-		-	-	-	-	1	-	-	-	-		-	-	-	1
Kimberly Clark	-	-	-	-	-	-	-		-	-	-	-	-	1	1	-	-		-	-	-	2
Reed	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	1	-	-	-	1
St. Regis	-	-	-	-	-	-	-		-	-	-	-		-	-	-	-	-	-	1	-	1
Shotton Paper	-	-	-	-	-	-	-		-	-	-	-		-	-	-	-	1	-	-	-	1
Stirling Stub.	-	-	-	-	-	-	-		-	-	-	1	-	-	-	-		-	-	-	-	1
Thomas Tait	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	1	-	-	-	1
Thames Board	-	-	-	-	-	-	-	-	-	-	1	-	1	-	3	-	-		-	-	-	5
Total	-	-	1	-	-	-	-		-	1	-	1	2	1	4	2	2	4	-	1	-	19

Source: PPI Twin-Wire Survey, 1984 and Installation lists of Twin-Wire Manufacturers.

necessary for those pulp and paper regions to look for alternative solutions. In the Scandinavia, the strategy was to diversify into higher value-added printing and writing paper which required much less wood content while in Japan it was to use chips and waste paper material as major sources of substitutes for pulp imports. The result is that twin-wire choices in these countries have reflected these national industrial structures and production specialisations: the overwhelming proportion of Canada's twin-wires are in newsprint production, with only few in the other paper grades while in other producing countries, varying proportions of twin-wires have been chosen. Thus it can be suggested that the choice of the twin-wire technology by all these major producing regions, especially Canada, has been to reinforce their production specialisations. In this case it is reasonable to suggest that had the twin-wire technology made its debut in paper grades other than newsprint, the adoptive behaviour of Canadian firms would have been different and this would have produced a different diffusion pattern.

In addition, the adoptive behaviour of pulp and paper firms at the global level seems to suggest that countries that are in close geographical proximity or have similar production specialisations tend to have similar adoptive patterns. Thus the choices made by Canadian and American firms, as depicted by the patterns they produced, were much more alike in terms of the number and time than those made by European firms, and vice versa. The similarity becomes even clearer with respect to specific grades. Thus firms in Finland and Sweden were very much alike in their twin-wire adoptive patterns with respect to newsprint, while a similar pattern exists among FRG, France and UK (Fig 5.4). In North America, Canada and the US, showed a similar pattern up to a point. In the case of printing and writing paper firms in Finland and FRG as were very much alike in their twin-wire adoptive patterns. In the case of Japan, twin-wire adoption rates for newsprint were much similar to the US and to a lesser extent Canada while in printing and writing paper, it was very similar to those of the US Linking these patterns to the regionalised nature of the global paper market, the direction of paper trade and other paper trade-related matters discussed in Chapter 3, these observations clearly reflect on the role of market competition and interdependence in shaping the technology choice process. Attention will now focus on the details of the diffusion pattern in Canada.

The Diffusion Pattern of Twin-Wires In Canada

The National Pattern

The first twin-wire machine was installed in Canada in 1968 by the Canadian International Paper (CIP) Inc which, in 1988, became part of the Canadian Pacific Forest Products (CPFP) Limited. By 1988, 22 Canadian firms had adopted the innovation, each of them having made at least one twin-wire machine installation in a total of about 42 plants[1] As already mentioned, Abitibi-Price had the most twin-wires, with 18 (17 per cent) of the 104 machines in the country. Other top firms in terms of twin-wire installations were Consolidated-Bathurst with 13 (13 per cent), CPFP Limited also with 13 (13 per cent) Kruger Inc with 11 (11 per cent), and Quebec-Ontario Paper (formerly called Ontario Paper) with 7 (7 per cent) (Table 5.13). By category of machines, the 22 firms showed some differences. All 18 machines of Abitibi-Price were top wires. So also were most of the firms with only one twin-wire installations. However, the majority of them had both pure twin-wires and top wires.

The Speed of Diffusion

The diffusion lags, calculated from the table and summarised in Table 5.14, ranged from 1 to 20 years and a mean diffusion lag of 12 years and no single modal value. Examination of the diffusion lags with the number of twin-wires (Table 5.13) indicate that Abitibi-Price, despite having the most twin-wire machines, was a late adopter. In addition, most of the late adopters in this context opted for the top wire category. The firm level unadjusted AFA for the period 1968 to 1988, was 1

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1. The number of firms takes into consideration the mergers that have taken place in recent years. Readers should note however that when discussing the timing of adoption and calculation of the speed of diffusion, the number of firms will be more since it will be necessary to consider firms from the perspective of when they did actually adopt the twin-wire machine, than their status as of 1988.

Table 5.13: **Canadian Firms With Twin-Wires As of 1988.**

Company	No. of Twin-Wires	Company	No. of Twin-Wires
Abitibi-Price	18	Kimberly Clark	3
Consolidated-Bathurst	13	Donohue	2
CPFP†	13	Rothesay	2
Kruger Inc	11	Bowater-Mersey	2
Quebec-Ontario Paper *	7	Eddy Forest	1
Domtar	6	Atlantic Packaging	1
Fletcher Challenge ††	5	James Maclaren	1
Boise Cascade	4	Stora Industries	1
MacMillan-Bloedel	4	Scott Paper	1
Reed Paper	3	Miramichi	1
F.F. Soucy	3	Weyerhauser	1

Number of firms: 22 Number of Twin-Wires: 104.
Three Dynaformers could not be classified

Source: PPI Twin-Survey, 1984 and Installation lists of Twin-Wire Manufacturers.
†CPFP = Canadian Pacific Forest Products. The firm includes former Canadian International Paper (10 twin-wires, including the two at its subsidiary, Dominion Cellulose) and Great Lakes Forest Products (3 twin-wires)
* Quebec-Ontario Paper was formerly known as Ontario Paper.
††Fletcher Challenge Canada comprises the former British Columbia Forest Products (BCFP) (2 twin-wires) and Crown Forest Industries (with 3 twin-wires).
Please note that for the purpose of analyses, the components of these two firms will be considered as separate entities at some point.

Table 5.14: **Inter-Firm Diffusion Lag of The Twin-Wire In Canada, 1968-1988**

Company	Lag (Years)	Company	Lag (Years)
CPFP	0	Reed Paper	14
Ontario Paper	1	Rothesay	15
MacMillan Bloedel	2	Scott Paper	15
Consolidated-Bathurst	4	Atlantic Packaging	15
Kruger Inc	4	James Maclaren	17
Boise Cascade	7	Bowater-Mersey	17
F.F Soucy	8	Domtar	17
Eddy Forest Products	8	Kimberly Clark	18
Abitibi-Price	13	Miramichi	19
Fletcher Challenge	14	Stora Industries	20
Donohue	14	Weyerhauser	20

Source: PPI Twin-Wire Survey, 1984 and Installation list of Twin-Wire Manufacturers.

in 3 months while the adjusted value was 1 in 11 months.

The inter-firm diffusion rate is calculated on the basis of the information in Tables 5.15 and applying equation (5.1). The Lockwood's directory from which the total number of companies were obtained counts parent and autonomous units of the same firm as separate entities. As a result the number of firms had to be adjusted to agree with the basis of classification used in the directory. Thus the number of firms in Canada used here is 33 instead of 22. Also, Lockwood's does not distinguish between how many of the companies are paper producers and for that matter may need a twin-wire. It was therefore assumed that all the companies produce paper. The resulting equation is given below by equation 5.3:

$$\ln (m(t) / n - m(t)) = -3.318 + 0.1349t \qquad (5.3)$$

$r = 0.97024$; $r^2 = 0.94137$; s.e of estimate = 0.19499; s.e. of slope = 0.00817.

Equation (5.3) is the firm-level diffusion curve, *r* is Pearson's correlation coefficient, s.e of estimate is the standard error of the regression estimate and s.e of slope is the standard error of the slope coefficient, 0.1349. On the basis of these statistics and a significant t-test, (t = 16.52, significant at both 1 and 5 per cent levels) we can say that the growth of Canadian firms accepting the twin-wire machine follows the logistic function of time, and the inter-firm rate of diffusion is 0.1349. Since the US constitutes the major market for Canadian pulp and paper firms, it will be important to compare these measures with those of the US

A Further Comparison With The US

At the firm level, 42 firms accounted for the 122 twin-wire installations in the US (Table 5.16). Assuming that all the 42 companies given by the Lockwood directory produce paper, 11 per cent of all the pulp and paper companies in the US had installed at least one twin-wire by 1988. The diffusion lags of these firms ranged from 2 to 20 years (Table 5.17) and the mean diffusion lag

Table 5.15: **Proportion of Canadian Pulp And Paper Firms with Twin-Wires, 1968-1988**

Year	No. of Companies *	No. of Twin-Wire Adopters *	Cumlative No. of Adopters	Cumulative %
1968		1	1	
1969	107	1	2	1.9
1970	93	2	4	4.3
1971/72	95	2	6	6.3
1973	98	0	6	6.1
1974	101	0	6	5.1
1975	100	2	8	8.0
1976	100	3	11	11.0
1977	95	1	12	12.6
1978	106	0	12	11.3
1979	102	0	12	11.7
1980	99	0	12	12.1
1981	98	2	14	13.2
1982	99	6	20	19.2
1983	99	3	23	23.0
1984	100	2	25	24.0
1985	99	4	29	29.3
1986	101	1	30	29.7
1987	105	1	31	29.5
1988	105	2	33	31.4

Source: Number of Companies were obtained from Lockwood's Directory.
Notes: Lockwood's treats the number parent companies and autonomous subsidiaries as separate entities. Also, it does not distinguish whether companies are engaged in only paper-making or pulping or both. These explain why the proportion of firms that had adopted the twin-wire technology by 1988 might seem so small. To reduce the effects that this classification problems might have on the results of the analysis, parents and subsidiaries of firms that had adopted the twin-wire technology were treated as separate entities.

was 11.4 years. These figures show that both firm-level and plant-level diffusion lags in the United States were longer than they were in Canada. The unadjusted AFA was 1 in 2 months, compared with Canada's 1 in 3 months while the adjusted equivalent was 1 in 8 months, compared to Canada's 1 in 11 months.

For the purpose of comparing the diffusion rates in the two countries a simple graphical analysis of firm-level first adoptions over time is first presented (Fig. 5.6). Looking at the Canadian

Table 5.16: **US Firms With Twin-Wires As of 1988**

Company	No. of Twin-Wires	Company	No. of Twin-Wires
Fort Howard Paper	8	Diamond International	1
James River Corp	8	Fletcher Paper	1
Georgia Pacific	7	FSC	1
St Regis	7	Mid-Tech Paper	1
Smurfit	6	Inland Empire	1
International Paper	6	Kimberly Clark	1
Bowater Southern	6	Lake Superior	1
Boise Cascade	5	Madison Paper	1
Champion International	4	Manistique	1
Garden State Paper	4	Marcal	1
Weyerhauser	4	Georgia Kraft	1
Willamette	4	Olinkraft	1
Gt. Northern Nekoosa	3	Owen-Illinois	1
S.D Warren	3	Potlach Corporation	1
Westvaco	3	Procter & Gamble	1
Augusta	2	Scott Paper	1
Consolidated Papers	2	South East Paper	1
Mead Corporation	2	Union Camp	1
North Pacific	2	Western Kraft	1
South West Forest	2	Wisconsin Tissue	1
Bear Is	1	Undisclosed	11
Chesapeake	1		

Source: PPI Twin-Wire Survey, 1984 and Installation lists of Twin-Wire Manufacturers.

curve, 4 main spurts interspersed with 3 distinctive lags can be identified. [2] In the first spurt, 1968 to 1970, three firms installed twin-wire machines followed by the first lag of two years. The second spurt, a shorter one occuring in 1972 with only two firm-level installations, is followed by a second lag, from 1972 to 1975, which is a year longer than the first. This is followed by a third spurt of a 4-firm-level installation, from 1975 to 1977, which is again followed by a much longer lag of 4 years, from 1977 to 1981. Then there is the last spurt with 16-firm-level installations spanning from 1981 to 1984.

In the US two main spurts interspersed with three distinctive lags can be identified. The first lag is from 1968 to 1970. In 1970, there was one installation followed by the second and the

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2 A distinctive lag is considered in this case as a lag longer than a year.

Table 5.17: **Inter-Firm Diffusion Lag of The Twin-Wire In The US, 1968-1988**

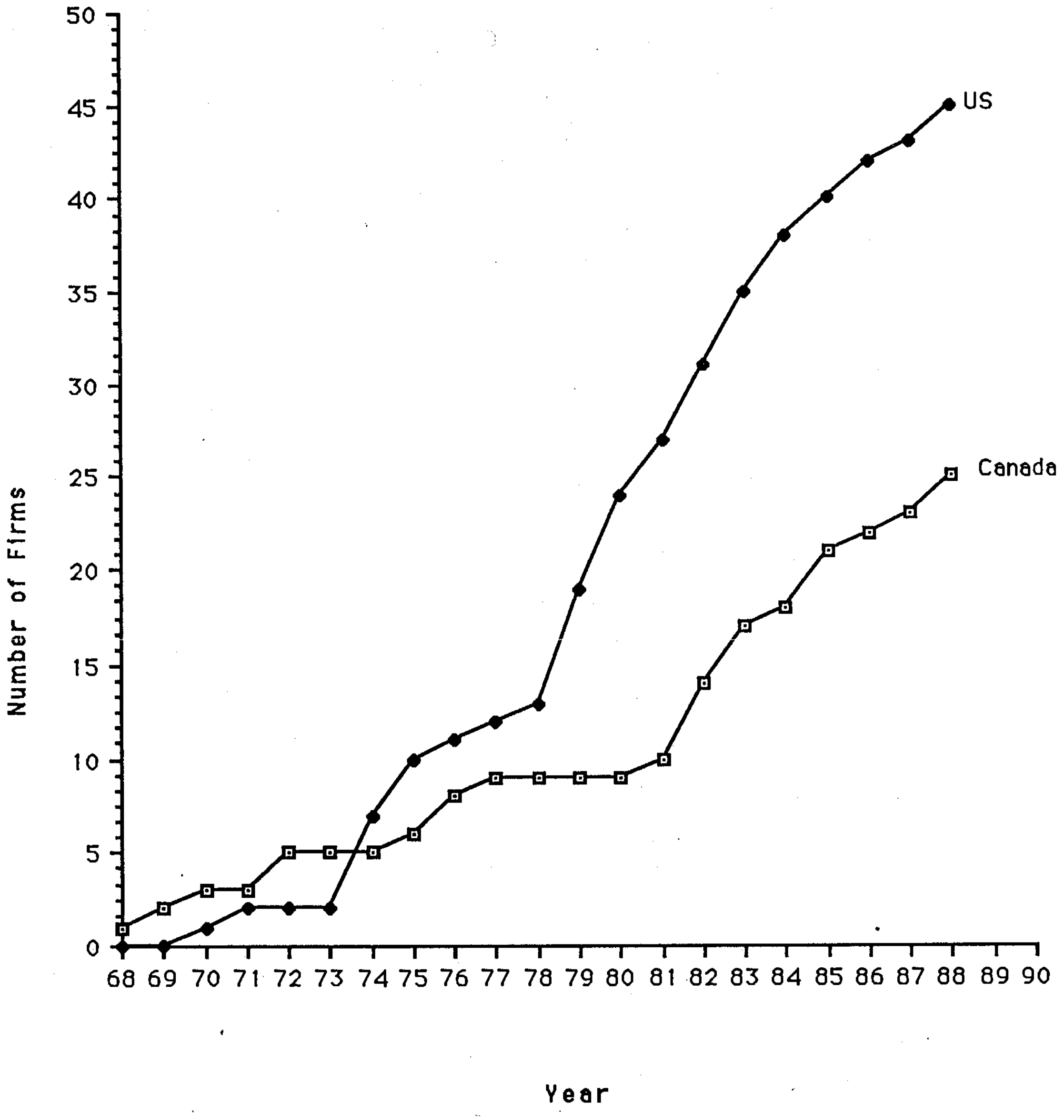
Company	Lag (Years)	Company	Lag (Years)
Weyerhauser	,2	Western Kraft	12
Olinkraft	3	Smurfit	12
Gt. Northern Nekoosa	4	Mead Corporation	13
Fort Howard Paper	6	Scott Paper	13
Garden State Paper	6	Inland Empire	14
International Paper	6	S.D Warren	14
St Regis Paper	6	Willamette	14
Champion International	7	Wisconsin Tissue	14
James River Corp	7	Augusta	14
South West Forest	7	FSC	15
Georgia Pacific	9	Westvaco	15
Marcal Paper Mills	10	Fletcher Paper	16
Bear Is Paper	11	Union Camp	16
Bowater Southern	11	Chesapeake	16
Diamond International	11	Manistique	17
Mid Tech Paper	11	Consolidated Papers	17
North Pacific	11	Kimberly Clark	18
Owens-Illinois	11	Georgia Kraft	18
South East Paper	11	Lake Superior	19
Potlatch	11	Madison Paper	20
Procter & Gamble	12		
Boise Cascade	12		

Source: PPI Twin-Wire Survey, 1984 and Installation lists of Twin-Wire Manufacturers.

longest lag of four years. From 1974 to 1975, the first major spurt occurred followed by the last lag from 1975 to 1977. From 1979 to 1988, twin-wire installations in the US has been one continuous spurt. Comparing the two curves it can be seen that in 1970 when the first US firm installed the first twin-wire, three Canadian firms had already installed twin-wire machines. By the beginning of 1974, five Canadian firms had installed twin-wires as against US's one firm. However, by the end of 1974, four US firms had installed twin-wires bringing the number of twin-wires in both countries at par. Three more adoptions in 1975 put the US above Canada in terms of the number of firms that had adopted the twin-wire technology. From 1975 to 1977, during the second US lag, two more firms adopted the twin-wire in Canada. However this was very short-lived because from 1978 to 1980, during the third and the longest Canadian lag, the US had as many as 10 new adopters, a number greater than the number of adopters in Canada from 1968 to 1977; 6 of them

FIG. 5.6: TWIN-WIRE ADOPTER FIRMS IN CANADA AND THE US

1968-1988



Source: Installation lists of Twin-Wire Manufacturers and
Pulp and Paper International's Twin-Wire Survey.

Table 5.18: **Number And Proportion of US Pulp And Paper Firms With Twin-Wires, 1968-1988**

Year	No. of Companies	Companies With Twin-Wires	Cumlative No.	Cumulative %
1968				
1969	452			
1970	383	1	1	0.3
1971/72	385	2	3	0.8
1973	413	0	3	0.7
1974	412	5	8	1.9
1975	410	2	10	2.4
1976	406	0	10	2.5
1977	407	1	11	2.7
1978	405	1	12	3.0
1979	404	7	19	4.7
1980	405	5	24	5.9
1981	402	3	27	6.7
1982	398	4	31	7.8
1983	394	4	35	8.9
1984	398	3	38	9.5
1985	401	4	40	10.0
1986	399	4	44	11.0
1987	406	1	45	11.1
1988	383	2	47	12.3

Source: Number of Companies were obtained from Lockwood's Directory
Notes: See Table 5.15.

adopting in 1979 alone.

On the basis of these graphical analyses, two observations can be made. First, the lags and spurts in both countries do not coincide. This could be an indication of the competition among the firms in the two countries. The second observation is that it is possible to conclude with earlier findings that even though US pulp and paper firms were late in adopting the twin-wire compared to Canada they became faster once they began to adopt the technology than their Canadian counter-parts who innovated the technology in the global industry. This seems to be further supported by fitting the linearised logistic curve to the US data in Table 5.18. Equation (5.4) below gives the twin-wire diffusion curve for US firms.

$$\ln (m(t) / n - m(t)) = -5.5403 + 0.20215t \qquad (5.4)$$

$r = 0.9436; r^2 = 0.89037$; s.e of estimate = 0.39032; s.e of slope = 0.1773

As can be seen, the statistics indicate that the growth of firms accepting the twin-wire machine over time is well approximated by the logistic function ($t = 11.40$, significant at both 1 and 5 per cent levels) and the diffusion rate is 0.202 compared to Canada's 0.135. Thus this result supports the findings of earlier work that US firms were faster in adopting innovations in the pulp and paper industries (Globerman, 1976).

Considering the basis of classification of firms on which this analysis was based, it is important to exercise some caution in interpreting these results. Moreover, it is important to remember that Canada's traditional strength in the paper sector of the global pulp and paper industry is in the production of newsprint, while the US has a more diversified pulp and paper industry structure. In this case it will be important to know whether the slightly faster adoption rate by US firms compared to their Canadian counterparts is not due to the large number of twin-wires it had in the production of other paper grades. To investigate this possibility, the number of adoptions in the two countries with respect to newsprint are compared. According to Newsprint Information (1988) data, there were 18 firms in Canada and 16 in the US that produced newsprint. Of the 18 firms in Canada, 16 of them had adopted the twin-wire technology by 1988. In the US, only 1 out of the 16 firms had not adopted the twin-wire technology (Table 5.19). This gives an a crude adoption rate of 94 per cent in the US and 89 per cent in Canada. In the US, the period of adoption, if the year of innovation is counted, spanned over a period of 18 years. In Canada, it was 20 years. In fact if only the year of twin-wire adoption for newsprint production in the US is taken into consideration, then the period of adoption in the US reduces to 12 years. The story is vividly depicted by Fig. 5.7, which is the graph of the inter-firm adoption of the twin-wire among newsprint firms in the two countries. Without any further curve-fitting exercise, it is clear that even in newsprint production, the US firms, even though adopted later than their Canadian counterparts, were faster in adopting the twin-wire than their Canadian counterparts, over the study period. Attention will now focus on

Table 5.19: **Newsprint Firms In Canada And The US As of 1988**

Canada		US	
Firm	Year of Adoption	Firm	Year of Adoption
CP Forest Products	1968	James River Corp	1974
Quebec-Ontario Paper	1969	Garden State Paper	1974
MacMillan-Bloedel	1970	Champion International	1975
Consolidated-Bathurst	1972	Bowater	1979
Kruger Inc	1972	Bear Is Paper	1979
Boise Cascade	1975	North Pacific Paper	1979
F.F. Soucy	1976	Southeast Paper	1979
Abitibi-Price	1981	Great Northern Nekoosa	1979
Fletcher Challenge	1982	Smurfit	1980
Reed Paper	1982	Boise Cascade	1980
Donohue	1982	Augusta Paper	1982
Rothesay	1983	Inland Empire	1982
Bowater-Mersey	1985	FSC	1983
Domtar	1985	Manistique	1985
James Maclaren	1985	Kimberly Clark	1986
Stora Forest Industries	1988	Stone Container	
Spruce Falls	-		
St. Raymond			
Firms with twin-wires = 16		Firms with twin-wires = 15	
Firms without = 2		Firms without = 1	

Source: Newsprint Information Committee, 1988

the twin-wire diffusion pattern at the regional level.

The Regional Pattern

Taking provinces as regions, Table 5.20 gives the regional distribution of twin-wires in Canada. The highest concentration of twin-wires is in Quebec, which alone accounted for 52 (51 per cent) of the 104 twin-wires in Canada. Next in the order were Ontario 21 (20 per cent), British Columbia, 10 (10 per cent), New Brunswick 6 (6 per cent) and Newfoundland 7 (2 per cent). By category of machines, 24 (65 per cent) of the 37 gap formers in the country were located in Quebec, 7 (19 per cent) in Ontario, 4 (11 per cent) in British Columbia and 2 (6 per cent) in New Brunswick. The distribution of top formers followed a similar pattern except that Newfoundland came after Quebec and Ontario before British Columbia (Table 5.21).

FIG. 5.7: TWIN-WIRE ADOPTION - U. S AND CANADA NEWSPRINT FIRMS

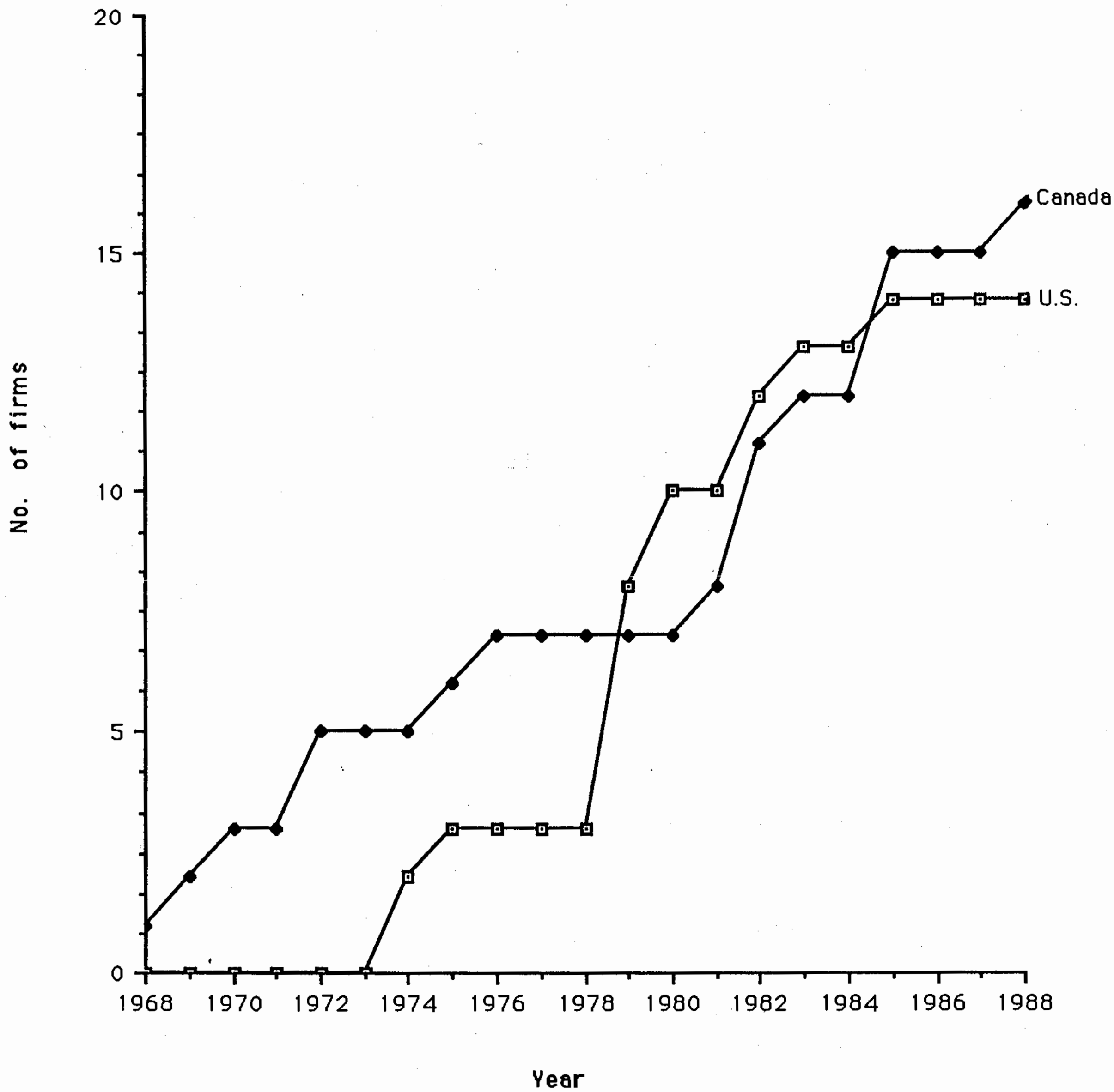


Table 5.20: **Regional Distribution of Twin-Wires In Canada As of 1988**

Region	Pure Twin-Wire	Top Wire	Total
British Columbia	4	6	10
Manitoba	-	2	3
New Brunswick	2	4	6
Newfoundland	-	7	7
Nova Scotia	-	3	3
Ontario	7	14	21
Quebec	24	29	53
Saskatchewan	-	1	1
Total	37	66	103

Source: PPI Twin-Wire Survey, 1984 and Installation list of Twin-Wire Manufacturers.

If the two recent mergers are discounted, then 24 firms accounted for these installations. By location of head office, 9 of the 23 firms had their head offices located in Quebec, 8 in Ontario, 5 in British Columbia and one each in New Brunswick and Nova Scotia, at the time of adoption. On the basis of the same criteria, Quebec was the first province to adopt the twin-wire technology. Next in the order were Ontario, 1969, British Columbia, 1970, New Brunswick, 1983 and Nova Scotia, 1988 (Table 5.21). The order changes to Quebec, British Columbia, Ontario, New Brunswick and Nova Scotia if the location of the plant where the machine was installed is considered. On the basis of the number of adopter and non-adopter firms, Ontario had the highest proportion of adopters (53 per cent), followed by Quebec and New Brunswick (both with 50 per cent), then British Columbia (45 per cent) and Nova Scotia (33 per cent) (Table 5.22). The inter-regional diffusion lags for the provinces on the basis of head office location were one year for Ontario, two years for British Columbia, 15 years for New Brunswick and 19 years for Nova Scotia. By adopter plant location, it was two years for British Columbia, eight years for Ontario, 13 years for Newfoundland, 15 years for both Manitoba and New Brunswick and 17 years for Nova Scotia.

Within the three provinces that had more than one-firm adoption, there were few differences in the speed of diffusion. In Quebec, the diffusion lag was 18 years for all the nine firms that had adopted the innovation. For Ontario, it was 17 years for the seven firms that had adopted while for

Table 5.21: **Twin-Wire Adopters In Canada By Region, Year of Adoption And Head Office Location**

Region	Firm	Year of Adoption	Head Office Location	Plant Location *
Quebec	CIP Inc	1968	Montreal	Trois-Rivieres, Que.
	Consolidated-Bathurst	1972	Montreal	Trois-Rivieres, Que.
	Kruger Inc.	1972	Montreal	Bromptonville, Quebec
	Eddy Forest Products	1977	Hull	Hull, Quebec.
	Donohue	1982	Quebec City	Amos, Quebec.
	Domtar	1985	Montreal	Dolbeau, Quebec.
	James Maclaren	1985	Montreal	Buckingham, Quebec.
	Miramichi	1986	Montreal	Newcastle, N.B.
Ontario	Ontario Paper	1969	St. Catherines	Baie Comeau, Quebec.
	Boise Cascade	1975	Toronto	Ft. Francis, Ontario.
	Abitibi-Price	1982	Toronto	Stephenville, Newfld.
	Reed Paper	1982	Toronto	Quebec City, Quebec.
	Atlantic Packaging	1983	Toronto	Scarborough, Ontario.
	Great Lakes Forest Prod.	1984	Thunder Bay	Thunder Bay, Ontario.
	Bowater Canada Ltd	1985	Hamilton	Liverpool, N.S.
British Columbia	MacMillan-Bloedel	1970	Vancouver	Powell River, B.C.
	BCFP	1982	Vancouver	Crofton, B.C
	Crown Forest Ind	1982	Vancouver	Campbell River, B.C
	Scott Paper	1983	Vancouver	New Westminster, B.C
	Weyerhauser	1988	Vancouver	Prince Albert, Saskatchewan.
New Brunswick	Rothesay	1983	St John	St. John, New Brunswick
Nova Scotia	Stora Forest	1987	Pt. Hawkesbury	Pt. Hawkesbury, N.S

Source: PPI Twin-Wire Survey, 1984 and Installation lists of Twin-Wire Manufacturers.
N.B = New Brunswick; N.S = Nova Scotia; Newfld = Newfoundland; B.C = British Columbia.

Table 5.22: **Regional Distribution of Twin-Wire Adopter And Non-Adopter Firms As of 1988**

Region	Adopters	Non-Adopters	% of Adopters
Alberta	-	2	0
British Columbia	5	6	45%
Manitoba	-	1	0
New Brunswick	1	1	50%
Nova Scotia	1	2	33%
Ontario	8	7	53%
Quebec	9	9	50%
Total	37	66	103

Source: PPI Twin-Wire Survey, 1984 and Installation list of Twin-Wire Manufacturers.

British Columbia it was 18 years for the five firms that had adopted. The AFA values on the basis of these statistics however show that acceptance or adoption of twin-wires have been fastest, on the average, in Quebec, being 1 in 2 years, while for Ontario and British Columbia, it was 1 in 3 years and 1 in 4 years respectively. Looking at the lag between the "provincial innovator" and the first adopter the picture was not different from that given by the AFA values. It was four years in Quebec, 6 years in Ontario and 12 years in British Columbia. In all the provinces, however, the lag reduced considerably with subsequent adoptions. What factors explain these patterns?

To explain these patterns, we can first use the conventional method by which the observed characteristics of adopter firms are tested against adoptive behaviour of firms. Thus we test the hypothesis that there is no association between a firm's size, a firm's possesion of R&D, a firm's ownership, a firm's organisational structure and a firm's location and twin-wire "adoption". To set the stage for testing the above hypothesis a categorization of pulp and paper firms in Canada according to the above-named factors was undertaken. Location was considered on the basis of head office location and was classified as either metropolitan or non-metropolitan. The three major cities Toronto, Montreal and Vancouver were considered as the metropolitan areas while other locations were considered as non-metropolitan. Firm size was based on the number of people employed in the firm at the time of first adoption. A firm with less than 5,000 people was categorised as small and

5,000 or more as large. At the plant level, plants with more than 500 employees were categorized as large and those with less than 500 were categorized as small. Firm ownership was considered Canadian if more than 50 per cent of the shares in the firm were owned by Canadians while R&D and organisational structure were categorised as firms with or without R&D facilities and multi-plant or single-plant firm, respectively. The list of firms were obtained from the Pulp & Paper Canada Annual Directories. Only the parents of firms engaged in paper production were considered. Also only first adoptions were considered.

The categorisation initially yielded a five-way contingency table which could be potentially analysed by log-linear and logit models (Wrigley, 1985; Ofori-Amoah and Hayter, 1989). However, the table contained too many empty cells so following the suggestion by Goodman (1971) and Upton (1986) the Table was collapsed into a number of two-way tables on which a series of simple chi-square tests and post-test residual analysis were performed.

The two-way categorisations are given by Table 5.23. The results of the chi-square test show that except for firm ownership, all the factors have significant association with the firms adoptive behaviour (Table 5.24). The residuals of the test show positive association between large firms and adoption, possession of R&D facilities and adoption and multi-plant firms and adoption (Table 5.25) and that these associations are statistically significant. These results agree with the findings of Gibbs (1982), Thwaites (1983) and Rees, Briggs and Hicks (1985). In terms of ownership, however, the test was not significant and the residuals indicate a non-significant but negative association between Canadian ownership and adoption. At the plant level, the results of the test on Table 5.26 are not different from the above (Tables 5.27 and 5.28). Large plants had a postive association with adoption while plants belonging to firms with R&D facilities were also postively associated with adoption. Again, plant ownership was statistically insignificant with adoption of the twin-wire.

Table 5.23: **Firm Size, Ownership And Firm Adoptive Behaviour**

Firm Size	Behaviour Users	Non-Users	Total
Small	6	22	28
Large	18	6	24
Total	24	28	52

Firm Ownership	Behaviour Users	Non-Users	Total
Canadian	14	17	31
Foreign	10	11	21
Total	24	28	52

Firm R&D	Behaviour Users	Non-Users	Total
Yes	16	6	22
No	8	22	30
Total	24	28	52

Firm Type	Behaviour Users	Non-Users	Total
Single-Plant	3	14	17
Multi-Plant	21	11	25
Total	24	28	52

Firm Location	Behaviuor Users	Non-Users	Total
Metro	16	7	23
Non-Metro	8	21	29
Total	24	28	52

These results are good in establishing broad structural characteristics at the national level. However, it should be noted that the factors firm size, firm type and possession of R&D facilities are all related. Therefore, if one shows positive association, it is very likely that the rest will also do the same. In addition, as far as regional variations are concerned, the results did not give much insight. No clear differences were found in firm sizes. For example, firms in Quebec, Ontario and

Table 5.24: **Results of The Firm Level Test**

Test	χ^2	D.F	Result
Firm Size and Behaviour	14.923	1	S
Firm Type and Behaviour	17.385	1	S
Firm Ownership and Behaviour	0.030	1	N.S
Firm R&D and Behaviour	10.835	1	S
Firm Location and Behaviour	9.095	1	S

For all tests N = 52; Critical χ^2 at 5 per cent level of significance = 3.84; S = Significant; N.S = Not Significant.

Table 5.25: **Adjusted Residual Values of The Firm-Level Test**

Firm Size	Behaviour		
	Users	Non-Users	Total
Small	-3.9	3.9	0.0
Large	3.9	-3.9	0.0
Firm Ownership	Behaviour		
	Users	Non-Users	Total
Canadian	0.2	-0.2	0.0
Foreign	-0.2	0.2	0.0
Firm R&D	Behaviour		
	Users	Non-Users	Total
Yes	3.3	-3.3	0.0
No	-3.3	3.3	0.0
Firm Type	Behaviour		
	Users	Non-Users	Total
Single-Plant	-2.8	2.8	0.0
Multi-Plant	2.8	-2.8	0.0
Firm Location	Behaviour		
Metro	3.0	-3.0	0.0
Non-Metro	-3.0	3.0	0.0

Table 5.26: **Plant Size, Plant Ownership, Firm R&D And Firm Behaviour**

Plant Size	Behaviour		
	Users	Non-Users	Total
Small	6	38	44
Large	36	16	52
Total	42	54	96

Plant Ownership	Behaviour		
	Users	Non-Users	Total
Canadian	31	40	71
Foreign	11	14	25
Total	42	54	96

Co. R&D	Behaviour		
	Users	Non-Users	Total
Yes	30	27	57
No	12	27	39
Total	42	54	96

Table 5.27: **Results of Plant Level Test of Association**

Test	χ^2	D.F	Result
Plant Size and Behaviour	29.933	1	S
Plant Ownership and Behaviour	0.0001	1	N.S
Plant R&D and Behaviour	4.497	1	S

For all tests, N = 96; Critical χ^2 at 5 per cent signicance level = 3.84;
S = Significant; N.S = Not Significant

Table 5.28: **Adjusted Residuals Values of The Plant Level Test**

Plant Size	Behaviour		
	Users	Non-Users	Total
Small	−5.5	5.5	0.0
Large	5.5	−5.5	0.0
Plant Ownership	Behaviour		
	Users	Non-Users	Total
Canadian	−0.0	0.0	0.0
Foreign	0.0	− 0.0	0.0
Co. R&D	Behaviour		
	Users	Non-Users	Total
Yes	2.1	−2.1	0.0
No	−2.1	2.1	0.0

British Columbia did not show significant differences in sizes. Again, significant differences in the timing of adoption by firms in the same city were also found. Thus in British Columbia, for example, the lag between the "regional innovator" and the subsequent adopters was 12 years. Differences in on-site R&D facilities existed at the regional level, particularly between British Columbia and Quebec. However, this difference diminished when R&D possessed by parent companies were taken into consideration.

It appears therefore that regional differences in adoption of the twin-wire could be due more to differences in resources and regional specialisations and other factors that relate to the corporate and managerial context of the firm. In particular, the concentration of newsprint capacity in the two provinces of Quebec and Ontario underlies why there is also the concentration of twin-wire machines in the two provinces. By virtue of its large tree species, British Columbia has historically emphasised pulp production while paper making can be to a large extent considered as a "by-product". In contrast, Quebec and Ontario have both emphasised paper-making as a result of smaller tree species and other historical factors. Thus over 80 per cent of Canada's paper firms and mills are located in Quebec and Ontario. It is, therefore, not surprising that more twin-wires should be concentrated in the two provinces.

In addition, this pattern also reflects on the point made by Martin et al (1979) that the two provinces were the pioneer regions for the industry in Canada. As a result, at the time that the twin-wire machines came into being, the two regions had much older machines in need of modernisation more than in the other provinces, hence their early lead. There is also market consideration. The Canadian pulp and paper industry is export-oriented. While the US constitute the major export market, Canadian pulp and paper firms have focussed on specific market areas mainly on the basis of geographical proximity so as to reduce distribution cost. Thus firms in British Columbia mainly trade with the Western US, specifically Southern California, while firms in the east, Quebec, Ontario and the maritimes, trade with the North-east US and the Mid-West. In this case the competitors of Canadian firms are the US firms who also trade in these regions. The behaviour of these firms regarding their twin-wire technology choice could therefore be important for the different times at which the firms in Canada adopted. Thus in 1970, both MacMillan Bloedel and Weyerhauser, the two of the largest firms on the west coast of North America both installed their first twin-wire machines.

Conclusion

The relevance of the spatial context to technology choice lies in its ability to place the adoptive behaviour of manufacturing firms in the global, national and regional settings of the industry in which the firms are operating in and in the questions that can be raised from these settings to aid further investigation for a better understanding of technology choice. The distribution of the twin-wire machine between 1968 and 1988 indicate significant spatial similarities as well as differences. In particular the adoption pattern reflect the various national , regional and local industrial structures and production specialisations. This indicates that technology choices are made to reinforce specialisations. In addition, pulp and paper producing regions in close geographic proximity, or with similar industrial structres or common markets tend to share comparable experiences and characteristics of adoption. Competition within and outside national boundaries tend to affect the technology choices, particularly the timing of the decision. Within Canada, differences in regional resource endowment, historical factors and market orientation seem to provide more insight into the adoption pattern, and choices that led to those patterns than such firm characteristics as firm size, firm R&D, firm type, and metropolitan location. Beyond these, questions as to why Canadian firms adopted the technology at the time they did and why differences exist in the in the tme at which individual firms adopted need to answered. Clearly, such questions have a lot to do with corporate objectives, strategies, investment history, innovativeness and other factors which can only be well understood by extending the analysis into the corporate or managerial context. This forms the focus of the next chapter.

CHAPTER VI

THE MANAGERIAL CONTEXT

Technology choice is ultimately the outcome of individual corporate or managerial decisions. Understanding the decision-making mechanism is therefore important to understanding the technology diffusion process by way of technology choice study. In this regard, there is evidence that firms behave differently depending upon the type of decisions they are confronted with and the circumstances under which those decisions are made. In routinised decisions, for example, certain laid down procedures are already in place and the decision-making process is nothing more than execution of those laid down procedures. In non-routinised decisions, this is not the case. Even where some kind of precedence exists, the firm may still have to exercise a lot of caution and judgement since such decisions entail a lot of capital investments and in most cases are closely tied to the very future of the firm. The ease and speed with which the firm takes to reach a decision and execute in this regard depends upon several factors such as the extent of urgency, the availability of resources, corporate innovativeness, corporate strategy, past investment history, production objectives. In a nutshell, the behaviour of a firm to issues requiring non-routine decisions such as technology choice depends on the specific situation of the firm at the point in time when the decision has to be made. This behaviour can only be understood by a detailed examination of the corporate or managerial environment of the firm within which the decision was made.

This chapter focusses on the corporate, managerial or organisational context of technology choice. In particular, it presents a detailed analysis of the choice of the twin-wire technology by six pulp and paper firms in Canada, with the view to answering the following questions: Why did the pulp and paper firms choose their twin-wire machines at the time they did? How did they do it? What factors affected their choices? What implications do the answers to these questions have for technological change studies and policy?

Method

Given its concern for getting to the roots of firm behaviour and given the type of questions involved the case study approach was used. Six firms were interviewed. For the purpose of confidentiality, the firms are designated Firms A through F.

The six firms were based in British Columbia and Quebec. There were several reasons why the firms were so selected. First, regional characteristics of the two locations were seen as a potential influence on the firms' decision-making (Chapter5). Second, the firms vary in terms of the basic "early" and "late" adopters dichotomy. The number of installations made by the firms was also taken into consideration. In 1984, the three Quebec firms that were included in the case study accounted for 20 out of the 49 (41 percent) of the twin-wire installations in the country. Together with the three installations in British Columbia, therefore, the case studies accounted for 47 per cent of all the twin-wire installation in Canada. These constituted 40 technology choice decisions of which 6 were first adoptions and 37 were subsequent adoptions. The experience of these firms in twin-wire technology choice was therefore deemed to be worthwhile. Moreover these installations represented all the major twin-wire options and also some interesting patterns that needed to be studied. In addition, it might be noted that in terms of ownership, both firms A and D were foreign-owned until 1981 and 1984 respectively; firms E and F were partly foreign-owned, the former now fully foreign-owned, and the latter still partly-owned and firms B and C were Canadian-owned at the time of the study. In terms of R&D, firms A, B, F and D either had their own R&D facilities or their parents had, when they made their first installations of twin-wires. Firms E and C did not. The mill locations and the twin-wire installations made by the three firms are given in Table 6.1.

Table 6.1: **Paper Machines of Case Study Firms Showing Twin-Wire Installations**

Firm	Mill	Machine No.	Type Of Machine	Start-Up Year
Firm A	Mill A1	1	Fourdrinier	
		2	Fourdrinier	
		3	Fourdrinier	
		4	Fourdrinier	
		5	Fourdrinier	
		6	Verti-Forma	1968
		7	Fourdrinier	
		8	Fourdrinier	
	Mill A2	1	Verti-Forma	1970
		2	Verti-Forma	1970
		3	Verti-Forma	1981
		4	Duoformer	1987
		6	F + Bel Form	1988
	Mill A3	1	Bel Baie II	1982
		2	Bel Baie	1983
		3	Fourdrinier	-
		4	Fourdrinier	
	Mill A4	1	H. Bel Baie III	1989
Firm B	Mill B1	1	Verti-Forma	1972
		2	F + Top Flyte	1986
		3	Verti-Forma	1982
	Mill B2	5	Fourdrinier	
		6	F + Top Flyte	1986
		7	F + Top Flyte	1989
		8	Papriformer	1982
		9	Papriformer	1973
	Mill B3	8	Fourdrinier	
		9	Fourdrinier	
		10	F + Dynaformer	1983
		11	Symformer	1989
	Mill B4	1	Papriformer	1975
		2	Papriformer	1975
		3	Bel Baie II	1979
		4	Bel Baie II	1986

Continued on the next page.

Table 6.1: **Paper Machines of Case Study Firms Showing Twin-Wire Installations** *(Conclusion)*

Firm	Mill	Machine No.	Type Of Machine	Start-Up Year
Firm C	Mill C1	1	F + Dynaformer	1984
		2	Papriformer	1972
		3	Bel Baie II	1981
	Mill C2	1	Fourdrinier	
		2	F + Top Flyte	1984
		3	Fourdrinier	
		4	Fourdrinier	
		5	F + Bel Form	1985
		6	Periformer	1981
		7	Papriformer	1975
		8	Coating	
		9	Coating	
		10	Bel Baie II	1989/90
	Mill C3	1	F + Top Flyte	1986
		2	F + Bel Form	1986
		3	Fourdrinier	
		4	F + Top Flyte	1985
		7	F + Symformer	1988
	Mill C4	1	Cylinder	
Firm D	Mill D1	1	Symformer N	1982
		2	F + Symformer R	1986
		3	F + H. Bel Baie III	1987
Firm E	Mill E1	1	F + H Bel Baie III	1987
		2	Fourdrinier	
		3	Bel Baie II	1982
Firm F	Mill F1	1	Fourdrinier	
		2	Fourdrinier	
		3	Fourdrinier	
		4	Periformer	1983

Source: Fieldwork, 1988
Notes: F = Fourdrinier.

Interviews

The firms were interviewed on the questions stated above. At least two top executives of the rank of Vice President or Manager and located at the head office were interviewed at different times. In the case of one firm, Consolidated- Bathurst, these included two former retired senior executives. These interviews were supplemented with similar interviews with plant-level personnel, mainly newsprint production managers and paper machine superintendents. Each interview lasted for about 2 to 3 hours after which further appointments were made where necessary for clarifications. At the plants, the interviews ended with tours of the plant site during which further questions were asked. Altogether, 16 senior executives at the head and plant offices were interviewed. After these interviews, a schedule on the reason and factors used in the evaluation of the various twin-wire options was prepared and circulated to the firms to complete. The purpose of this was to obtain some general idea of how technology choices are made by the firms. A copy of the schedule is included in the thesis as Appendix. Some information from the interviews of the paper machine suppliers were also used to verify the answers given by the 16 respondents.

The chapter is organised in two parts. The first examines the main components of the decision-making process leading to the choice of the twin-wire technology by the six firms. The second deals with the timing of the adoptions. Throughout, an attempt is made to separate the first adoptions from subsequent adoptions in order to be consistent with the analysis in the previous chapter. Clearly, this separation is important from the point of view of the manufacturing firm as the first installation or adoption of a technology is historic and pathbreaking the effect of which can either enhance or hinder further adoptions. Also, it allows the examination of the effect of experience on technology adoption.

The Decision-Making Process

The stages of the decision-making process leading to adoption of a new technology were outlined in Chapter 2 as *Stimulus*, *Decision* and *Implementation*. The stimulus stage is the stage where the firm goes through some need-provoking experiences regarding an existing technology and a new technology that eventually push the firm into taking action as to whether or not to adopt the new technology. The decision stage is where the firm takes the necessary actions to respond to the need while the implementation is the set of inter-related steps geared towards carrying out the responses made at the decision stage. As it was pointed out in Chapter 2, each of these components is complex in itself, with the complexity increasing according to the range of choice of options available and thus according to the particular time when the decision is made. Moreover, each of these stages is an integral part of a wider investment decision which in turn contribute towards corporate strategy. In this regard, it is important to remember that a paper machine is itself very expensive and generally requires investments in related processes. In fact, in 13 out of the 24 capital investment projects for which I could get the required information, the investment in paper machines were over 50 per cent of the total investment in expansion or modernisation or both projects. In 8 out of the 13 cases, the proportion was over 70 per cent (Table 6.2). In turn, these investments were part of the long run modernisation and expansion strategies of firms. In the following sections these components are examined with reference to the adoption of the twin-wire technology by the six case study firms.

The Stimulus Stage

All the six firms identified two main types of stimuli: an external stimulus and an internal stimulus. The external stimulus constituted the major stimulus and consisted in the need to improve product quality and to increase production as a result of the changing market conditions. In particular, respondents indicated that improvements in printing technology led to demand by press houses for high quality paper which was not two-sided, exhibited the least amount of streaks as well as reduced linting in the printing room and thus had good printability. In addition, increasing demand for paper products meant increasing production output alongside improvement in quality. In order to respond to these demands, there was the need to expand and also modernise newsprint as well as pulping capacities. These required a higher speed paper machine which would also be able to produce paper with the required qualities. As indicated in Chapter 4, the existing paper machine, the Fourdrinier, was by these standards obsolete and the only paper machine that could meet these requirement was the twin-wire. Thus the twin-wire became a focus of the exapnsion and modernisation strategies of the firms (Table 6.2).

In addition to these stimuli that were common to all the firms, there were other external stimuli which played significant roles, particularly in the first adoptions of the early adopters. These were supplier initiatives, behaviour of competitors and government financial incentive programme. All the three early adopters identified the important role of supplier initiatives in their first installations. Black Clawson, who invented the first twin-wire on grades other than board, for example invited over 200 firm executives from major pulp and paper firms to its laboratory at Watertown to see the invention. Both firms B and C made mention of similar moves by Dominion Engineering to market its Papriformer. Behaviour of competitors was particularly important for Firm B where Firm A's installation of the Verti-Forma at its Mill 1, which was next door to the Firm B's mill, motivated the mill manager to raise the issue of twin-wires at Mill Manager's meetings. In the same vein, government financial incentive provided an external stimulus for Firm C's first adoption. The company needed to rebuild and modernise its No.2 paper machine and realised that a former with a higher drainage capacity would be the best option. At that time the twin-wire idea was still new and the only one available was the Verti-Forma. However, about the same time, Dominion Engineering had produced the first commercial prototype of its Papriformer and wanted a commercial trial. To get Canadian inventions on the world market the Canadian government at that time had a programme called Programme for the Advancement of Industrial Technology

Table 6.2: **Investment Context of Twin-Wire Adoptions By The Six Case Study Firms**

Firm	Mill	Year of Inst.	Nature of Investment	Cost of Machine (Cdn$)	Tot. Investment Cost (Cdn$)
Firm A	Mill A1	1968	N/A	N/A	N/A
	Mill A2	1970	N/A	N/A	N/A
		1970	N/A	N/A	N/A
		1981	Newsprint Expansion and development	N/A	$38m.
		1987	Modernisation of paper machine, pulping system and shipment	$44m.	$59m
		1988	Modernisation of paper machine and pulp mill	$8.9m	$10.6m
	Mill A3	1982	Mill modernisation and expansion	N/A	$146.6m
		1983	Same as above	N/A	Same as above.
Firm B	Mill B1	1972	Modernisation and expansion	$1.5m	$2.2m.
		1982	Modernisation and expansion	$61.3m	$68.1m
		1986	Paper machine speed-up and modernisation	$10.5m	$11.7m
	Mill B2	1973	Millwide modernisation	$6m	$11.2m
		1982	Mill modernisation and production increase	$32.4m	$51.9m
		1986	Modernisation and pulp mill expansion	$6.5m	$76.2m
		1988	Same as above	$5.9m	Same as above.
	Mill B3	1983	Mill modernisation and paper machine speed-up	$7.3m	$9.5m
		1989	Mill expansion and modernisation	N/A	$235.5m
	Mill B4	1975	Modernisation	$5m	$17.3m
		1975	Same as above	$0.4 million	Same as above.
		1979	Expansion and modernisation	$26.3m	$29.02m
		1986	Modernisation	$41.4m	$43.7m

Continued on the next page

Table 6.2: **Investment Context of Twin-Wire Adoptions By The Six Case Study Firms** *(Conclusion)*

Firm	Mill	Year of Inst.	Nature of Investment	Cost of Machine (Cdn$)	Tot. Investment Cost (Cdn$)
Firm C	Mill C1	1972	Miscelaneous	$0.4m	N/A
		1981	Expansion paper machine speed-up	N/A	$36.2m
		1984	Expansion of Thermomechanical Pulp (TMP) plant	$3.4m	$6.1m
	Mill C2	1975	N/A	N/A	N/A
		1981	Modernisation and expansion, including TMP plant and computerised process control	$12m	$56.5m
		1984	Modernisation and expansion	$4m	$31.1m
		1985	Modernisation and expansion	$4.7m	Same as above
	Mill C3	1986	Modernisation and mill upgrading including TMP and bleach plant improvements	$13m	$59m
		1986	Same as above	$17m	Same as above
		1988	Expansion and modernisation including paper machine electric drives and TMP lines	$35m	$98.5m
Firm D	Mill D1	1982	N/A	N/A	N/A
		1986	N/A	N/A	N/A
		1987	Modernisation and expansion including TMP capacity increase	$20.4m	$69m
Firm E	Mill E1	1982	Expansion	$150m	$150m
		1987	Expansion	N/A	$N/A
Firm F	Mill F1	1983	Expansion	$58m	$93.5m

Source: Pulp & Paper Canada, 1968 to 1988 issues on Capital Spending
Notes: Costs figures are only estimates.

(PAIT) which offered financial assistance to companies to try new Canadian inventions. As part of this programme, firm C received some financial assistance to purchase and install the first Papriformer, with further guarantees that in case the machine failed, Dominion would replace it with a fourdrinier machine and the Government would pay for the loss of production. Firm C found the financial arrangements quite attractive and risk-worthy and so decided to purchase and install the machine.

The main internal stimuli identified were the self-perceived innovativeness of company executives; company perceptions of future market changes and the innovative history of companies. The innovativeness of company executives was stressed by all the three early adopters as the most important internal source of stimulus. Closely related to this factor was the ability to make fairly accurate predictions of future market trends. For Firm B, this was attributed to the experience gained from extensive travels by senior Company executives throughout Europe, which accounted for 20 per cent of the Company's markets.

A, B and C saw their innovative history as another important internal source of stimulus. Firm B particularly placed a lot of emphasis on this. Respondents indicated that it had always been the philosophy of the company to be ahead of its competitors by building on known products; being opportunistic in using technological breakthroughs to upgrade the base product; by being quality oriented; and by making maximum use of existing facilities at each mill. This strategy had enabled the company to innovate in a number of areas, including the development of the first centrifugal cleaners which improved runnability on the machine and in the pressroom; the manufacture of the first machine-finished rotogrades through the introduction of selective screening in their ground wood department; the back-tender friend which came to be used on many machines in the world to improve the caliper uniformity of the product. Thus in the 1960s, when more began to be desired of the quality of the Fourdrinier paper these companies began to experiment with all kinds of paper-making methods including spraying starch on the wire, the dandy rolls and other sections of the Fourdrinier during the sheet forming process so as to reduce linting on the paper. These efforts provided an adequate internal preparation for the acceptance of the twin-wire before and after it had proven to be superior.

The Decision Stage

The Corporate Task Force

All the six firms responded by establishing a Corporate Task Force to look into the viability of adopting the twin-wire technology. With respect to the first adoptions, it was not possible to clearly identify the membership of the Task Force, particularly for the early adopters because most members were no longer with the company. However, all the three firms indicated that the idea was discussed at least among the top executives of the firm before the final decisions were made. At both firms A and B the discussion solicited advice from the R&D Departments. In the case of Firm C, advice was sought from the Central Engineering Department. Among the late adopters the membership differed in composition depending upon the nature of the firm. For Firm D, it consisted of personnel from the Head Office in which was outside the country and was headed by the Vice President of Technology. For Firm F, it consisted of representatives of all the three mills of the company and was headed by the Corporate Vice-President of Ventures. For Firm E, it consisted of executives of its pulp and paper mill division.

With reference to subsequent adoptions, no differences were found among the five firms which had made multiple adoptions. All of them indicated that the relevant response decisions were made by a Corporate Task Force, which consisted mainly of mill and Head Office officials depending upon the firm. At Firm A it consisted of representatives from the R&D, Sales, Operations, Paper Makers, Engineering, Purchasing and Environmental Departments. At Firm B, it consisted of the Director of R&D, the Manager of Newsprint Manufacturing, the Mill Manager and an engineer from the Central Engineering Group. At firm C, as well as Firm E, it was the Central Sales Department and the officials of the mill concerned. In the case of Firm D it was completely composed of plant executives in contrast to the head office domination in the first adoption. This change was due to the fact that the company had changed ownership and unlike the former owners, the new owners adopted a decentralised policy by which the subsidiary firm was granted a greater degree of autonomy in making such important decisions. In all the cases the Corporate Task Force was responsible to such higher executives as the Vice President of Newsprint, Vice President of Manufacturing, Vice President of Finance and the President.

Types of Decision Made

First Adoption

The types of decisions to be made differed between first adoptions and subsequent adoptions. With reference to the first adoptions, the Task Force was asked to make three inter-related decisions. First, it was to choose between the twin-wire technology and the then existing single-wire technology. Second, if the twin-wire option was selected, the Task Force was to decide whether to rebuild existing machine or install a completely new one. Third, for firms with several paper plants a decision also had to be made as to the best locations for the new technology. In some cases new sites options were also considered.

The Technology Choice Decision

The technology choice decision involved a comparison of the twin-wire technology and the Fourdrinier or the machine the firm was using before the twin-wire (except for Firm F). The criteria used differed among the firms and reflected their corporate production objectives and specialisations. All the six firms decided in favour of the twin-wire. The firms found the twin-wire more superior in terms of product quality and speed, two qualities which were essential in meeting the needs of the changing market. In the case of Firm D, the Task Force went further to recommend the specific twin-wire unit, the Valmet Symformer N, to be installed. For Firm F, increasing production capabilities and product enhancement technologically meant reduced basis weight (which averages about 10 lb per 3000 square feet in tissue) and at the same time improving paper strength. Reduced basis weight meant lighter sheet which, in turn, needed a high-speed machine while improved paper strength needed multi-layer forming. The two types of technologies that existed were suction breast forming and twin-wire forming. Suction breast forming had a speed limitation since it could only run up to 45 feet per minute. Besides it did not have capabilities for multi-layer forming. In contrast, twin-wire forming had a higher speed potential, capabilities for multi-layer forming and easy operational control. Any technology for high speed multi-layer forming was thus confined to the twin-wire machine.

The Location Decision

The factors that affected the location of the first installations differed among the firms. In the case of Firm A, the location of the machine at Mill 1 was due mill size and type of product. By nature, the first generation modern twin-wires were primarily designed for newsprint grade. However, having built the first commercial twin-wire prototype, Black Clawson realised that pulp and paper firms were unwilling to try the new machine at the expense of their existing machines, even though, as already, indicated over 200 people from major pulp and paper firms honoured the invitation to go down to Watertown to see the pilot machine. While the reasons for this reluctance cannot be easily explained, some clues became evident in the interviews that it might have been due to risk element involved with using the Verti-Forma. In particular, the first commercial unit was built to replace the conventional fourdrinier section of the paper machine. This meant that pulp and paper firms had two options if they decided to adopt the machine: they could either shut down one paper machine and install the Verti-Forma in place of the fourdrinier section of the paper machine while using the old press and dryer sections or they could purchase new press and dryer sections alongside the Verti-Forma. Of the two, the latter was the cheapest. Yet, the risk involved was still high for most firms at that time depending on the number of paper machines the firm had and whether it was prepared to shut down one of those machines. As a result when Firm A's executives later on decided to experiment with the machine they chose the firm's Mill 1 because it had the largest number of paper machines (eight) and therefore it was estimated that the risk of shutting one of them down to be replaced by the Verti-Forma would be at a minimum. In addition, the mill was producing flyer cards which needed good printability on both sides and since the pilot runs on the Verti-Forma showed a reduction in the two-sidedness, it was considered that the mill will be the best place to locate the new machine even though it was on a trial basis.

In the case of Firms B and C the location of the first machines was based on the firms' newsprint expansion and rationalisation plans. Within these plans, machines were designated for improvements on the basis of their product and capacity. Thus machines which had largest capacity and/ or poorest quality product were modernised first. Thus, the choice for Firm C was the No. 2 machine located at Mill C1. However, for Firm B its largest machine was machine Mill B3 and at that time the machine was relatively new and the sheet it produced was quite good and acceptable on the market. Consequently, there was no urgency to convert the machine. Attention was therefore focussed on the next largest machine which happened to be the No.1 machine at Mill B1.

Economic considerations influenced the locations of the first machines of both Firms D and F. In the case of the former, the Company's two newsprint mills on the North American west coast, one located in Oregon and the other in British Columbia, were asked to submit estimates on how much it would cost to install a new paper machine at the plants. Apparently, Mill D1, located in British Columbia, was selected because its estimates were lower. [1] In the case of Firm F, three main options were considered by the Task Force. The first, was to locate the machine at the Western Division mill, the second was to locate it at one of the Eastern Division mills and the third was to locate it at a new site. The Task Force opted for the Western Division plant at Mill F1 largely because infrastructure cost was going to make the new site option very expensive. The most important factor that led to the location of the new machine at Mill F1 was transportation cost. Canada is the major market outlet for the Company's products. However, as a result of the high

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1 . This is only a speculation. It was not very clear at the time of the interview why the Mill D1 was chosen because the whole decision was made at the parent's head office, which was located outside Canada.

cost of transporting the finished products from the western part to the eastern part of the country, the Company had divided the national market between its two divisions. The Western Division served as far east as Thunder Bay and the rest of the country was served by the Eastern Division. This not only give a larger market to the Western Division, but also a sort of 'monopoly' over its share of the market since there was no other tissue producer in the western part of the country. In contrast, the Eastern division had to share its market with other competitors. The economic advantage of locating the facility Mill F1 was therefore higher. All these decisions were made with a great deal of consultation with the parent company which was located outside Canada.

Subsequent Adoptions

Once the first adoptions were made, the technology choice decision regarding subsequent adoptions shifted from whether or not to accept the twin-wire technology to when and where the next installation could be made. The process of arriving at this decision therefore was different from the first, particularly for the early adopters. All the five firms that had had multiple twin-wire installations, indicated that as part of their regular organisational routine the Central Sales Department, usually sent periodic feedback of the situation in the product market to the Manufacturing Department at the Head Office and also to mills concerning how well their products were received on the market. When there was any indication that a new paper machine was needed, the Manufacturing Department, usually the Vice President of Manufacturing, asked for proposal for fund approval, which would then be incorporated into the firm's short, medium or long term plan. To prepare the proposal, the Task Force usually undertook a preliminary search and assessment which differed in details from firm to firm. At Firm A, the process involved a general assessment of the type of product, size and tonnage of machine. At Firm B several meetings were held between the Central Sales Department and the officials of the mill concerned. In the case of Firm C, cost estimates from potential suppliers were also included. The officers responsible for making these decisions depended on the Company and included the Vice President of Newsprint, Vice President of Manufacturing, Vice President of Finance and the President.

With respect to location, subsequent adoptions by firms, which had made multiple installations, followed largely the principles set out by the first location decision. As already explained, Firm A located its first twin-wire machine at its Mill A1 primarily because the plant was large enough in terms of the number of paper machines to warrant the experimental nature of the exercise. Once the experiment proved successful, it became necessary to apply an appropriate citerion to the location of subsequent twin-wires and the criterion the firm chose was the marketability of a machine's product. Since Mill A1 was not a newsprint mill, this criterion shifted the focus on other newsprint mills, particularly Mill A2, which received two Verti-Forma installations in 1970, and subsequently to Mill A3 and A4. Thus as at 1988 when this fieldwork was done, Mill A1 had not received any more twin-wire machines other than the first Verti-Forma installation in 1968. This confirms the observation made in chapters 4 and 5 that firms make technology choices to reinforce production specialisations.

The Decision Implementation Stage

The Implementation Team

Having made the broad decisions of the technology option and location, the decision-making process entered the implementation stage. The first step in the implementation stage was to establish what may be referred to as the Implementation Team. Unlike the Corporate Task Force, this team was given the specific task of implementing the decisions of the Corporate Task Force. The size of the team ranged between four to six members and usually consisted of officials at the mill/plant which needed the machine and consisted of representatives of the paper makers, engineers, the mill manager and a project manager, who usually headed the team. To the membership of the team was added an engineering consultant, except in the case of Firm C which did not use any consultant. With the exception of Firm F, which used the Centurion Engineering group, all the firms indicated that H.A Simons of Vancouver was the engineering consultant mostly used. The activities of the implementation team was monitored by the Corporate Task Force.

The Search Process

The first task of the Implementation Team was to search for the appropriate twin-wire option. The distinguishing features of this search process from that of the decision stage was its intensity and extent of details. Primarily, the process consisted of an examination of the range of choice of twin-wire machines available to the firms at the time. The nature of the process varied between the early and late adopters. For the three early adopters, the process was limited for their first adoptions since there were not many twin-wire options and the suppliers were in close proximity. Indeed in the case of Firm A's first installation the issue was decided when the decision was made to install the twin-wire, since there was only one twin-wire available at that time. For both Firms C and B there were only two twin-wire options available, namely the Verti-Forma and the Papriformer and the suppliers of these machines, namely Black Clawson and Dominion Engineering, were in close proximity to the firms.

For the later adopters the search process became more extensive. The respective teams of all the six firms embarked on extensive travels to mills of other pulp and paper firms with twin-wire installations as well as R&D laboratories or pilot plants of machine manufacturers to familiarise themselves with latest developments. Firm E mentioned that they did a literature review before the travel. In order to cut down on cost, the team did not travel together in most cases but members individually visited specific mills where specific questions about the particular machines they were using were asked. The usual places visited were Canada, the US, Federal Republic of Germany (FRG) and the Scandinavia. Next the team came together to prepare detailed specification on the features of the machine the firm wanted and sent it to suppliers. The suppliers then bid after which they were invited to give detailed presentations on their bids. Technology-related decisions made at the *decision stage* sometimes placed a limit on the number of suppliers that could be invited. Thus when the decision was to install a pure twin-wire, suppliers such as Valmet which specialises in hybrid formers would not be invited (see Chapter 4). Proximity of suppliers, exchange rate-related issues and size of supplier firm were also mentioned as other factors that determined the suppliers to be invited. References were frequently made to the inability to invite Voith, the German paper machine builder, because of the strong German mark. Similarly such minor machine builders like Escher Wyss was never invited by any of the firms studied. The presentation usually lasted a whole day and often was repeated at two or more other times depending upon the firm and the requirements of the project, after which the Team evaluated the various options. An engineering consultant, where employed by the firm, would help the team to do the evaluation.

Evaluation of Machine Options: General

The evaluation of twin-wire options by the six firms were quite complex and varied by the whether firms were early or late adopters, and the methods and factors that were considered important. Evaluation did not constitute a major exercise particularly in connection with the first twin-wire installations by the early adopters because the range of choice were so limited. However, as the range of choice of twin-wires broadened, this became a major exercise and systematic procedures were developed. With reference to methods employed two firms, A and E, used a Kepner-Tregoe (K-T) technique, a rank-weighting technique for evaluating investment decisions. Firm F also used the technique but only partially. The remaining firms did not use any specific technique but evaluated their various options by discussion of several issues and concensus.

Whichever approach that was used, a number of factors were cited in all evaluations. These related to the supplier, the type of machine and the firm's own needs and resources. Supplier-related factors included confidence commanded by the supplier, technical support being offered by the supplier, supplier's delivery time and special financial incentives being offered by the supplier. Machine-related factors included product quality, machine quality, speed and machine cost while company/firm-related factors included the company's own previous experience, other company's experience, company's financial and investment position and type of product/furnish. A generalised categorisation of these factors on the basis of their frequency of use by the case study firms and their calculated modal and mean category values are given by Table 6.3 from which it can be seen that such machine-related factors as product quality and machine quality were most frequently categorised as *very important.* In contrast some supplier-related factors like confidence in the supplier, technical support from the supplier and company-related factors like experience of the company as well as others were frequently categorised as *important* while machine cost, type of furnish and delivery time, were most frequently categorised as *somewhat important.* Personal reasons were *not considered* in most of the cases. By the mean category value, product quality comes out clearly as the most important factor followed by machine quality, technical support expected from the supplier, experience of other Companies, confidence in the supplier, type of product, machine cost, Company's own experience, type of furnish, delivery time and personal reasons in that order. Among the less important factors, the one that was emphasised the most was price. The following comments were typical of the reasons given why this was the case.

> The difference in capital cost of the machines is relatively small compared to the potential production rate of the machine. For example if you know that a machine will perform at a certain speed it would not take long for the machine to pay back the difference. The difference between $10 million and $11 million is insignificant (A retired Vice President of Newsprint Manufacturing).

> While the overall economics of a project dictate whether or not to go ahead, economic considerations are not so important in buying paper machines as the ability of the machine to produce the required product. In the pulp and paper industry the issue is not to buy the least cost machine or the most expensive machine but what people have confidence in (A Chief of Engineering Services).

These comments do not mean that price was not considered. It was but in most of the cases it was only after product quality and machine quality factors had been considered.

Of factors relating to product quality, formation and streaking were categorised as *very important,* basis weight, sheet symmetry and retention, pinholing as important, while Scott bond and wire cloth marks were between *important* and *not important* category (Table 6.4). By the mean category values, formation and streaking were the most important, followed by basis weight, sheet symmetry, pinholing, retention, wire cloth marks and Scott bond. Table 6.5 also gives the details of the factors related to machine quality and indicates that headbox operation and former operation

Table 6.3: **General Factors Used By The Six Firms In Evaluating Twin-Wire Options**

Factor	Firm D	Firm E	Firm F	Firm A	Firm B	Firm C	Mean Cat. Val	Mod. Cat. Val.
Product quality	1	1	1	1	1	1	1	1
Machine quality	1	-	1	1	1	1	1.4	1
Confidence In Supplier	2	2	1	3	2	3	2.2	2
Machine cost	3	3	2	2	3	2	2.3	3
Supplier tech. supp.	2	1	2	2	2	2	1.8	2
Type of product	2	2	1	-	1	5	2.2	1/2
Type of furnish	5	2	1	2	2	5	3.0	3
Firm's own experience	3	2	2	2	2	3	2.3	2
Other firm's experience	2	3	2	2	2	1	2.0	2
Delivery time	3	3	3	2	4	3	3.0	3
Personal reasons	5	2	5	5	5	5	4.5	5

Source: Fieldwork, 1988.
Explanation of numbers: 1 = Very Important; 2 = Important ; 3 = Somewhat Important; 4 = Not Important; 5 = Not considered.
Mean Cat. Val. = Mean Category Value. It is calculated by finding the mean of all the values of each factor.
Mod. Cat. Val = Modal category value.

Table 6.4: **Product Quality Factors Used By The Six Firms In Evaluation of Twin-Wire Options**

Factor	Firm D	Firm E	Firm F	Firm A	Firm B	Firm C	Mean Cat. Val.	Mod. Cat. Val.
Formation	1	1	1	1	1	1	1	1
Streaking	1	1	1	1	1	1	1	1
Basis weight	2	2	1	-	2	1	1.6	2
Sheet symmetry	2	1	1	2	2	2	1.7	2
Scott bond	4	4	5	-	2	2	3.4	2/4
Retention	1	2	2	3	2	3	2.2	2
Wire/cloth marks	2	3	2	-	1	3	2.2	2/3
Pinholing	2	2	1	-	2	2	1.8	2

Source: Fieldwork, 1988.
Explanation of numbers: 1 = Very Important; 2 = Important; 3 = Somewhat important; 4 = Not Important; 5 = Not Considered
Mean Cat. Val. = Mean Category Value.
Mod. Cat. Val. = Modal category value.

were the most important factors.

While these factors give some insight into the factors that the six firms used in the evaluation of their machines, it was emphasised by all respondents that each adoption decision was unique, and evaluations depended upon the circumstances under which they were made. The result is that no single evaluation took all the factors into consideration at the same time. An attempt to portray this is given by Table 6.6. In the table, N indicates the number of twin-wire adoption decisions made by each of the six case study firms. The figures under each firm indicates the number of those decisions in which the factors listed in column 1 of the table received most emphasis or was used in conjunction with other factors to make the decision. Thus Firm D had made 3 twin-wire adoption decisions at the time of the study. Both product quality and machine quality factors received emphasis in all 3 decisions, while machine cost was considered in 2 of the decisions and delivery time in 1. Similarly, of the 13 decisions made by Firm B, product quality was used as an evaluation factor in 8 of them, machine quality in 5 of them and so on. In total, product quality was used in 24 (60.1 per cent) of the 40 twin-wire adoption decisions made by the six case study firms, machine quality in 14 (35 per cent), machine cost in 9 (23 per cent) of them while delivery time and personal reasons were both used in 2 (5 per cent) of the 40 decisions. In particular, it was also discovered that even the same factors were given different ratings on the same machine unit at different times. In order to gain more insight into these evaluations, the details of all the installation decisions made by the firms studied are given in Table 6.7 and specific examples are discussed.

Evaluation of Machine Options: Firm by Firm Examples

The six firms exhibited a wide range of differences in the evaluation of each machine installed. This was not only among themselves but even within the firm itself. Thus each installation was unique and decisions were based on the exigencies of the situation. At Firm A the first adoption was experimental and since there was only one twin-wire, the choice was made once the decision to change over to the twin-wire had been made. Evaluation was based on product quality and

Table 6.5: **Machine Quality Factors Used By The Six Firms In The Evaluation Of Twin-Wire Options**

Factor	Firm D	Firm E	Firm F	Firm A	Firm B	Firm C	Mean. Cat. Val	Mod. Cat. Val.
Headbox operation	1	2	1	-	1	1	1.2	1
Former operation	1	2	1	-	1	1	1.2	1
Wet end general	3	1	2	-	3	3	2.4	3
Wires	3	-	2	-	3	4	3	3
Start-ups/shut-downs	4	2	1	-	3	4	2.8	2/4
Learning Curve	5	4	2	-	3	5	3.8	5

Source: Fieldwork, 1988.
Explanation of numbers: 1 = Very Important; 2 = Important; 3 = Somewhat Important; 4 = Not Important; 5 = Not Considered.
- = Rank/category not given.
Mean Cat. Val.= Mean category value.
Mod. Cat. Val.= Modal category value.

Table 6.6: **Frequency Of Use Of General Factors In The Technology Choice Decisions**

Factor	Firm D N = 3	Firm E N = 2	Firm F N = 1	Firm A N = 9	Firm B N = 13	Firm C N = 12	Total N = 40
Product quality	3	2	1	5	8	5	24 (60.1%)
Machine quality	3	1	1	3	5	1	14 (35%)
Confidence In Supplier	2	-	1	1	-	-	8 (20%)
Machine cost	-	2	-	1	3	3	9 (23%)
Supplier tech. supp.	-	2	-	-	-	1	3 (8%)
Type of product	-	-	1	-	1	-	2 (5%)
Type of furnish	-	-	1	-	1	-	2 (5%)
Firm's own experience	-	-	-	2	2	2	6 (15%)
Other firm's experience	-	-	-	-	1	-	
Delivery time	1	1	-	-	1	-	2 (5%)
Personal reasons	-	1	-	-	-	1	2 (5%)

Source: Fieldwork, 1988.
N = Number of twin-wire decisions made.

speed. The two installations that followed in 1970 were evaluated in the same way. However, the owners of the Company at that time, used confidence in supplier/supplier preference to rule out the only other option to the Verti-Forma, the Dominion Engineering's Papriformer, to install two more Verti-Formas at the Mill A3. The rejection was an example of the role of supplier confidence mentioned in the one of the comments above. It also confirms the importance of the technological environment, discussed in chapter 4, to technology choice by firms.

The parent company did not have confidence in Dominion Engineering and thought Dominion was being subsidized by the Canadian government to enable it sell its products which to them was sub-standard. Indeed, there was a 22.5 per cent duty on foreign built machines at that time to make it more expensive to buy machines from outside. Apart from this, General Electric (GE) bought into Dominion Engineering about the mid-1950s, and even though GE did not buy control, it took over a substantial part of Dominion. Given that GE was interested in hydraulics, it devoted about 60 per cent of the resources of Dominion to hydraulics to the neglect of the Paper Machine Division at Lachine. Dominion, therefore, did not have the staff, research facilities and financial backing to undertake R&D activities as the other machine builders and in most cases it had to rely on PAPRICAN at Pointe Claire for a lot of its research. Due to these inadequacies, the parent firm did not have any confidence in both the supplier and the machine it produced. Thus the Papriformer was rejected. Supplier preference again was used to augment product quality in the selection of the Bel Baie II for 1982 installation at Mill A3 and the Bel Baie III scheduled to start-up in 1989 at Mill A4. The request for Bel Baie II and Bel Baie III for both installations came from the partners of the projects. At Mill A3, the firm, which owned 1/3 of the plant, made the request because its own domestic market had a special likeness for Beloit machine products. At Mill A4 the request was made by a publisher firm, as a condition for agreeing to become a partner in the project.

Financial considerations, though not regardered as very important, did become very important in certain cases, depending upon the time and special circumstances. The choice of the

Table 6.7: **Summary Details Of Twin-Wire Evaluation By The Six Firms**

Firm	Installation	Machines Compared	Machine Selected	Major Evaluation Factors
Firm A	1968, Mill A1	Fourdrinier, Verti-Forma	Verti-Forma	Speed, product quality, experimental
	1970, Mill A2	Verti-Forma, Papriformer	Verti-Forma	Previous experience, confidence in supplier
	1970, Mill A2	Same as above	Verti-Forma	Same as above
	1981, Mill A2	Verti-Forma	Verti-Forma J	
	1982, Mill A3	Bel Baie II	Bel Baie II	confidence in supplier, product quality, machine quality.
	1983, Mill A3	Bel Baie II	Bel Baie II	Same as above
	1987, Mill A2	Duoformer Symformer Bel Form	Duoformer	Financial incentive
	1988, Mill A2	Bel Form	Bel Form	Product quality.
	1989, Mill A4	Symformer, Duoformer, H. Bel Baie III	H.Bel Baie III	Best formation, speed, partner preference
Firm B	1972, Mill B1	Verti-Forma, Papriformer	Verti-Forma	Product quality, speed, future of industry.
	1973, Mill B2	Papriformer,	Papriformer, Verti-Forma	Speed, price
	1975, Mill B4	Verti-Forma, Papriformer, Bel Baie	Papriformer	Retention, speed, previous experience
	1975, Mill B4	Verti-Forma, Papriformer, Bel Baie	Papriformer	Retention, speed, previous experience
	1979, Mill B4	Papriformer, Bel Baie II	Bel Baie II	Formation, price
	1982, Mill B1	Verti-Forma V, Papriformer, Bel Baie II	Bel Baie II	Formation

Continued on the next page.

Table 6.7: **Summary Details Of Twin-Wire Evaluation By The Six Firms** *(Continuation)*

Firm	Installation	Machines Compared	Machine Selected	Major Evaluation Factors
Firm B	1983, Mill B2	Verti-Forma V, Papriformer, Bel Baie II	Papriformer †	Retention, additional cost, formation
	1984, Mill B4	Verti-Forma V, Papriformer, Bel Baie II	Bel Baie II	Product quality, industry standard, confidence in the supplier.
	1984, Mill B3	Dynaformer, Bel Form	Dynaformer	Product quality
	1987, Mill B1	Top Flyte, Bel Form	Top Flyte	Formation
	1987, Mill B2	Top Flyte, Bel Form	Top Flyte	Formation
	1989, Mill B2	Top Flyte, Bel Form	Top Flyte	Formation
	1990, Mill B3	Symformer, H. Bel Baie III, Duoformer F, Symformer HS	Symformer	Type of product; type of furnish; other firm's experience.
Firm C	1972, Mill C1	Verti-Forma, Papriformer	Papriformer	Speed, cost, financial incentive
	1975, Mill C2	Verti-Forma, Papriformer	Papriformer	Previous experience
	1981, Mill C2	Papriformer, Periformer	Periformer	Product quality
	1981, Mill C1	Bel Baie II	Bel Baie II	Formation (product quality)
	1984, Mill C1	Dynaformer, Bel Baie II, Bel Roll	Dynaformer	Previous experience, preference for roll formers
	1984, Mill C2	Symformer R, Top Flyte, Duoformer	Top Flyte	Product quality
	1985, Mill C3	Same as above	Top Flyte	product quality
	1985, Mill C1	Bel Form, Top Flyte, Symformer R	Bel Form	Cheapest investment
	1986, Mill C3	Bel Form	Bel Form	
	1986, Mill C3	Top Flyte, Symformer R	Top Flyte.	Product quality
	1988, Mill 3	Symformer R, Duoformer	Symformer	Proximity to supplier
	1989/90, Mill C2	Bel Baie II	Bel Baie II	Financial incentive ††

Continued on the next page.

Table 6.7: **Summary Details Of Twin-Wire Evaluation By The Six Firms** *(Conclusion)*

Firm	Installation	Machines Compared	Machine Selected	Major Evaluation Factors
Firm D	1982, Mill D1	Symformer N, Papriformer, Bel Baie II	Symformer N	Machine quality, ease of operation, ease of changing cloth, ease of maintenance, confidence in supplier, delivery time; product quality.
	1986, Mill D1	Symformer R, Bel Form, Dynaformer, Top Flyte	Symformer R	Speed, machine quality, confidence in supplier, product quality
	1987, Mill D1	H. Bel Baie III	H. Bel Baie III	latest technology, machine quality, product quality
Firm E	1982, Mill E1	Symformer N, Bel Baie II	Bel Baie II	product quality, price, delivery time, cost of spare parts, technical support from supplier, personal reasons
	1987, Mill E1	Bel Form, Symformer R, Duoformer F, Top Flyte, H. Bel Baie III	H. Bel Baie III	Same factors as above plus suitability of technical design of machine.
Firm F	1983, Mill F1	Bel Tissue, Periformer	Periformer	Supplier's experience, technical support, reduced installation cost, compatibility of machine configuration with process technology.

Source: Fieldwork, 1988.
† : The original choice was a Bel Baie II but Head Office changed the decision due to reasons indicated.
†† : The machine was actually purchased in 1979 with availability of tax dollars
H. Bel Baie III = Horizontal Bel Baie III

Duoformer and the Bel Form for the 1987 and 1988 installations, respectively, by the firm are examples. In the case of the Duoformer the purpose of rebuilding the No. 4 machine at Mill A2 limited the choice to the true top-wire family right from the beginning. Thus comparison was made among the Voith Duoformer, the Valmet Symformer and the Beloit Bel Form. The search team were particularly impressed with what they saw at the research laboratories of both Voith and Valmet. However, Voith had a very attractive financial programme attached to the purchase of the machine. This was the Brazilian Government's "FINES" programme which allowed 10 per cent payment on the purchase of any Brazilian built machine and an 8-year payment period starting not until after the machine had been delivered. This financial programme proved very attractive so a Voith Duoformer was chosen over its competitors. However, in the following year when the "FINES" programme had ended and the same machines were compared for rebuilding the No. 6 machine at Mill A2, the Bel Form was chosen because of higher product quality.

At Firm B machine-related factors dominated most of the evaluation process. In 1972 a Verti-Forma was installed on the basis of product quality. However, in 1973 installation another Verti-Forma was rejected in favour of the Papriformer because even though it had better formation it was a slow machine. Besides, Firm A was having problems with its Verti-Forma installations so the Company decided to wait until Black Clawson had corrected the problems. Finally, it was more expensive. For the same reasons, except price, the Verti-Forma was again rejected in favour of two more Papriformers that were installed in 1975. However, in 1982 after Black Clawson had improved the Verti-Forma J model into the Verti-Forma V model, the Verti-Forma was chosen over the Papriformer and the Bel Baie II because it had the best formation. This is also an example of how R&D activities in the life of an innovation, in this case by the supplier, can influence technology choice, and thus subsequent adoption.

A similar trend was identified with the evaluation of the 1979, 1983, 1984 and also the 1975 installations by Firm B. All the installations involved comparison of the same machines, namely the Bel Baie II and the Papriformer. In 1975 the Bel Baie II was rejected because it had very low first pass retention. In 1979 it still had a low retention. Yet it was accepted because, in addition to the confidence the Company had in Beloit, it was the Company's first Beloit twin-wire machine and so it received a discount. In 1983 the Implementation Team selected a Bel Baie II for No.9 machine at Mill B2. However, the Head Office reversed the decision in favour of the Papriformer because the Bel Baie still had a low retention and would need installation of disc filters before it could perform at a total retention level as the Papriformer, and this involved additional cost. In addition, it was considered that with a Papriformer already running at the Mill B2 another Papriformer would save the Company the cost of new spare parts. Yet in 1984 the Bel Baie II was chosen for the Mill B4 because it had become the industry-wide best former in terms of formation, even though it had not overcomed completely the retention problem.

The effect of type of product, and for that matter furnish, was exemplified in the choice of the Valmet Symformer for start-up in 1989 at Mill B3. The installation was aimed at producing speciality grades, particularly fine paper, which required the use of fine pulp and a high amount of clay. A comparison with other speciality mills showed that all the speciality machines using the twin-wire concept were not pure twin-wires but hybrids. So this limited the choice to the hybrid family of machines. Three machines were considered: the Beloit Horizontal Bel Baie III, the Valmet Symformer F and the Voith Duoformer F on the basis of formation, lint, two-sidedness and retention. All three were good in removal of lint. The Horizontal Bel Baie III was the best in both formation and removal of two-sidedness but the poorest in retention. For newsprint, the Bel Baie III would have been the choice but for fine paper production it was unsuitable because fine paper production require a furnish with a high clay content so as to increase the fineness of the furnish. Therefore if such a furnish is run on a machine with a low first pass retention such as the Horizontal Bel Baie III, the loss will be much greater than what might be acceptable. The Bel Baie III was thus rejected. Both Valmet and Voith had just introduced the high speed versions of their machines, the Symformer HS and the Duoformer H and wanted the Company to consider them as well. These too were rejected because both machines were most suitable for newsprint. The final comparison was therefore made between the Symformer F and the Duoformer F (F in both cases for fine paper) and on the basis of product quality, machine quality, proximity and confidence in the supplier, the Valmet Symformer F was chosen. [2]

Firm C's first twin-wire adoption, as already pointed out, was solely evaluated on the financial incentives that came along with it. No technical input by way of evaluation was made and the advice of the Central Engineering Department of the company against the project was even overruled. However, the success of this first installation coupled with relatively lower price and best formation made the Papriformer, once again, the choice for the firm's next two twin-wire installations. The selection on the Bel Form for the No.6 machine at Mill C2 and the Dynaformer for the No.1 machine at Mill C1 as well as the Valmet Symformer for the Mill C3, however, emphasised different factors. The Bel Form was chosen because it was cheapest for the purpose. The No.6 machine required rebuilding. It was known that the machine had a short life span left, about five years. However, it was also realised that if the machine could be rebuilt at a minimum cost such that the investment would pay back in a relatively shorter time, the net return on investment would be worthwhile. Evaluating the various options for doing this, it was realised that the best option would be to rebuild the machine by retrofitting it with a top-wire. The decision was made that any top wire at all which would minimise the cost, could pay back in two years and at the same time produce better quality sheet than previously would do. The Bel Form met these criteria and was therefore chosen.

The Dynaformer was chosen for the No.1 machine at Mill C1 because of the mills own previous experience with one of its earlier installations. A Bel Baie II, which had been previously installed at the mill, gave the mill so many problems that at one point the sheet was becoming difficult to sell. As a result, when the need for the next installation came up, the mill decided that it would not install any formers that dewatered over stationery elements. This left the Dynaformer

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2. The Symformer F was to be built in Montreal , while the Duoformer was to be built in Brazil.

as the only roll former option because Beloit's Bel Roll had not yet been proven. The Valmet Symformer was chosen in 1988 for the same mill because of speed, quality and proximity of supplier. Before the company had found it difficult to purchase from Valmet because Valmet machines for the North American market had to be built in Finland and this increased the cost and the delivery time. However, following the Valmet purchase of Dominion in 1984, Valmet machines could be built and sold from Lachine, Montreal.

In the case of Firm D, the evaluation of the Symformer N was in part predetermined by the decision of the Corporate Task Force to install the machine. The task of the Implementation Team therefore was to compare the Symformer N to other options that were available. While respondents were not able to identify clearly the reasons for the Task Force's decision, it was speculated that in addition to good paper-making, the machine was chosen because of the conservativeness of the parent company. This was because, as a hybrid former, the Symformer N incorporated features of both the old Fourdrinier machine and the twin-wire and since the twin-wire idea was still new at the time the decision was being made the Company considered it safer to stay mid-way between the two technologies. The Implementation Team compared the Symformer N with two other twin-wire machines, the Dominion Engineering's Papriformer and the Beloit Bel Baie II. Among the check list of the engineers were quality in the design, manufacturing and parts, as well as ease of changing major component parts, while those of the operations party included maintenance with particular reference to ease of adjustment, ease of changing the clothing, as well as ease of control. On the whole the Papriformer turned out to be the cheapest in terms dollars. However, for reasons given by the above comments on price and for the same reasons that made Firm A's parent to reject Dominion's Papriformer, the parent of Firm D also rejected the Papriformer. The Bel Baie II cost roughly the same as the Symformer N but Beloit would only be able to deliver the machine in 24 months while Valmet would deliver in 18 months. As a result the Valmet Symformer N was chosen.

The Symformer R was chosen for the 1986 installation because of machine quality and supplier preference. The choice had to be restricted to top-wires because the purpose of the installation was to rebuild a fourdrinier machine. Three other top-wires were considered namely, the Beloit Bel Form, the Dominion Dynaformer and the Black Clawson Top Flyte. No Voith machine was considered because they were too expensive. The Bel Form was rejected because it did not add any improvement in formation. Besides there was a problem with flooding and Beloit had to do some work on it. Also reports from mills operating the machines were conflicting even among officials of the same mill. The Top Flyte was too slow even though it had a very good formation. The Dynaformer could not be considered because the Symformer R itself was a direct improvement upon the Dynaformer. In addition, the performance of the Symformer N installed in 1982 had generated a lot of confidence on the part of the Company in Valmet.

In the case of the 1987 Horizontal Bel Baie III the choice of the machine was based on a directive of the Chief Executive that the plant should look for a machine that would either meet or beat any of the Company's competitor on the market. At that time the horizontal Bel Baie III was the latest twin-wire on the market and no commercial application had been made. However, pilot trials run at Beloit Wisconsin proved very satisfactory with the Implementation Team so the machine was chosen.

For its first twin-wire adoption in 1982 Firm E compared two machines, which at that time were considered the best machines for newsprint in the industry, namely the Beloit Bel Baie II and the Valmet Symformer N, and chose the Bel Baie II. The choice was based on first product quality, then price, delivery time, downtime for installation, technical support from supplier, cost of spare parts and other personal viewpoints. While the same procedure was used for evaluating machines for the subsequent installation in 1987 the choice of the Horizontal Bel Baie III over the Bel Form, the Symformer R, the Duoformer F and the Top Flyte was further augmented by special machine features. Originally, the Company had considered installing a completely new paper machine. However, the huge investment outlay required to purchase and install a new and pure twin-twire and its ancillaries, such as drives, dryer, motor and generators were beyond the company. Consequently, the rebuild option by way of a top wire installation was favoured. In the event, compared with all the top wire options listed above, the Horizontal Bel Baie III had a special technical design and operating principle that converted its retrofit into a pure twin-wire. Specifically, when a Fourdrinier machine is retrofitted with a top wire former, the bottom wire receives the stock first before the top wire catches it. In contrast, when a foudrinier is retrofitted with a Bel Baie III, both wires catch the stock immediately just as it occurs in pure twin-wire formers. As a result of this quality, the Horizontal Bel Baie III was selected.

Firm F chose the KMW Periformer over the Beloit Tissue for its first installation because of supplier and machine-related factors . First, KMW had more experience in twin-wire tissue technology than Beloit and therefore commanded confidence of the firm. Second, it offered more favourable technical support services. For example, KMW had a research facility where the Company could check its pulp. Third, it offered a pre-installation assembly of the whole machine with all its ancillary parts which reduced the actual installation cost. In addition to these supplier-related factors, the headbox of the Periformer was particularly suited to the process technology used by the Company at Mill F1. The furnish of the company usually consisted of mixes kraft pulp, groundwood pulp and CTMP. Because of its long fibre characteristic kraft pulp has the best retention rate during the forming procees. In addition, it has better adhesive property and thus able to stick to the Yankee dryer better than the other two pulp types, in the absence of which blisters may occur during drying which in turn causes holes to form in the paper. This meant the headbox of the machine should be such that if all the three pulp types are blended the kraft pulp will form the layer closest to the wire and to the Yankee dryer, after the sheet has been transferred by the felt to the dryer section. It was found that with the Beloit configuration, if the pulps were fed in the right order the groundwood, instead of the kraft pulp would end up against the Yankee dryer, while with the KMW configuration, the Kraft pulp would end up against the Yankee dryer.

Purchase, Installation and Start-Up

After the evaluation process was completed the the decision-making process entered the last stage which involved the purchase, installation and start-up of the machine. The Team met the supplier whose bid was accepted for further discussion on the specification, the price, management of construction, installation and services to be offered by supplier after which a formal order was made for the machine. The duration for building new machines was about 18 months while construction work at the site usually took 6 months making it a period of 24 months from the machine-order date to start-up date. All the firms employed an engineering consultant to do the pre-installation construction work with the mill engineers, usually the same consultant employed at the evaluation stage. The installation was usually made by the suppliers, the engineering consultant and the engineering staff of the firm. No significant differences were found between the first adoptions and subsequent adoptions as well as early and late adopters.

Having examined the main stages in the decision-making process leading to the adoption of the twin-wire by the six firms, the discussion will now focus on why the firms adopted the technology at the times they did. Time here will refer to the date of adoption which will be defined as the start-up date of the machine.

The Timing of The Decisions

First Adoptions

A common explanation given by conventional studies regarding the differences in the time firms adopt a given technology is that by nature some firms are laggards while others are innovators. In addition, these laggard firms are also considered in most cases to be small in size. The distinction between leaders and laggards has relevance for this study especially with respect to first adoptions. At the same time, the timing of decisions is affected by other factors. In particular, technology choice is an essential element of corporate strategy and therefore the timing of whether or not to adopt a given technology is closely tied in with the firm's strategy and its investment decision-making. In addition, other factors such as the firm's predecision environment, investment history and other corporate objectives may be important.

Given that the decision to adopt the twin-wire technology was triggered off by a stimulus, a good way to answer the question is to examine if there were differences in the times at which the firms received their respective stimuli. All six firms claimed a common external source of stimuli, namely the changing conditions in the product market. In addition, it was indicated by all the firms, that these conditions did not become serious until the end of the 1970s specifically 1978, the very year in which such late adopters as Firms E and F initiated moves towards the adoption of the twin-wire technology. If this was the case why then were A, B and C early in adopting the technology? The main reason that made them adopt the the twin-wire technology at the time they did was the ability of their respective executives at that time to accurately foresee and predict the promise the twin-wire technology held for the future of the paper industry, and therefore were able to finally respond to supplier initiatives. Thus a respondent at Firm B commented:

> In 1964- 1965, we said we would put in a twin-wire. People waited to see how it would run. We did not have enough reason to take the chance. In 1967, the Manager of Newsprint at that time foresaw that in the next 3 years offset printing would overtake letterpress in the pressroom so even though the Vice President Of Manufacturing did not like the idea, he forced it upon him

Firm C's first installation in which the advice of the Central Engineering Department against the installation was overruled by the owner-Chief Executive is another clear example of the role of foresight. In addition, corporate investment history and investment climate also contributed to the timing of the first adoption. Firm A, the innovator, was offered a special deal for taking the risk. Firm B was committed to sound investment because of its difficult financial position in the period before its first adoption and Firm C decided to make use of the government incentive.

Innovativeness of firm executives as a factor in early adoption received further confirmation from suppliers who divided their customers, that is pulp and paper firms in general , into two: leaders and followers. The first were those who wanted to be innovative and the latter were those who were forced to adopt the technology the technology either because of competition or because of environmental problems. While most of the leaders were big, size was not as important as enterpreneurial ability. Thus the Corporate Manager of Sales for Valmet commented:

> There are two types of customers- those who want to be leaders and those who want to be followers. Leaders would ask for 'leadership advantages', which would be in a form of price and this actually gives them just about one or two years advantage because once the machine has been installed all the rest will do the same. Most leaders are big but not all of them. It all depends on enterpreneurial ability. Example is Firm C. They put in the first Papriformer. At that time they were not big. But they took the chance and paid very little for the machine because Dominion was offering it at a low price since it was the first one. Another example is Inland Empire which was quite small, yet put in the first Dynaformer. The machine was offered to every Company in Canada but they all refused to take it.

However, the three late adopters in the study differed from one another as to why they adopted the twin-wire late and at the time they did even though all three knew about the twin-wire technology in fact about the same time as the early adopters. Thus while the decision-making process at Firm D towards the adoption of the twin-wire began in 1972, the year Firms B and C installed their machines, it was not until 1982 that the machine was finally installed. Since the whole decision was made outside the country, it was not possible to obtain any information from respondents as to why it took such a long time (10 years) for the installation. However, a few clues were either mentioned or discovered in the course of the research which give some insight into the long delay. First, it was indicated that the firm's philosophy was to be a follower. As a result since the twin-wire idea was still new back in 1972, it might be that the Company was being cautious. The second clue was the decision-making process itself. Thus the Manager of Engineering Services commented:

> The decision to buy twin-wire machines affect a pulp and paper firm so much that it is always made very high up the Company's organisational structure. Firms do not just wake up one morning to say 'Let us buy a paper machine'. New ideas are usually discussed in a number of informal settings among staff, and among counterparts in the company so that by the time the company gets to making a decision there is almost a consensus within the company and among decision-makers.

The highly centralised administrative and decision-making mechanism of the parent company at that time could therefore affect the decision-making process contributing to the delay. Apart from this, examination of installations by the parent company showed that the first twin-wire machine of the parent company was actually installed in 1975 at Camas, Washington. Thus even though this was a tissue machine the investment involved could have delayed subsequent installations. For Firm E, it was past investment history that delayed its twin-wire adoption. The company installed two fourdrinier machines in 1964 and 1968, when the twin-wire machine was still not an acceptable innovation in the industry, and did not think the market pressure for twin-wire was strong enough to be worth another major investment.

In the case of Firm F the twin-wire technology was non-existent , as far as its products were concerned, until 1972 because that was the year in which the first twin-wire tissue machine became available for commercial production. However the incidence of market pressure was again not strong enough to use the twin-wire until 1978 when the review of its usual 5-year plan revealed a need for twin-wire. Besides, the parent firm had installed its first twin-wire machine in Alabama, US 1981 and since it had to approve all major investments, such as twin-wire installation, by Firm F this might have affected the timing of adoption in 1983.

Subsequent Adoptions

With reference to subsequent adoptions all the five firms that had made multiple adoptions initially considered them as part of their newsprint rationalisation plans which ranged between 2 to 5 years in duration. However, a number of factors were given by respondents as to why these plans could not always serve as a useful guide regarding the timing of subsequent adoptions. Among these were experience with the performance of previous adoptions, change in ownership, corporate production emphasis and world market conditions and behaviour of competitors. Again the five firms differed in terms of which factors were important in affecting their subsequent installations.

In the case of Firm A, the success of the first machine motivated two more Verti-Forma installations in 1970 at its Mill A2. However, the next installation was not until after 1981 when five more installations were made: two in 1982, and one each in 1987, 1988 and 1989. Production emphasis and market pressure on the company accounted for the 12-year lag between 1970 and 1982 during which no twin-wire installations were made. As already pointed out, respondents indicated that the pressure from press room for higher quality papers, and for that matter twin-wire papers, did not actually intensify until after 1978. In connection with the change in production emphasis, it was indicated that Firm's parents until 1981, were not big newsprint makers. In fact, their speciality was in kraft, linerboard and board. So there was not much investment in newsprint. However, after 1981 this production emphasis was changed towards newsprint and paper grades other than board by the new owners of the Company. More twin-wire installations thus became necessary.

At Firm B corporate decisions to change the production emphasis similarly triggered off further twin-wire installations in 1973 and 1975. The 1973 installation stemmed from a decision made in 1972 to expand the Mill 2 into a full newsprint mill. At the same time, another pulp and paper firm had shut down one of its newsprint machines because the wet end of the machine was too old, and was selling all the ancillary parts - the press and the dryer sections - at a very cheap price. Around the same time, the Company became aware of the fact that Dominion Engineering Company was promoting its Papriformer. Firm C had installed the first commercial unit of the new machine in the same year and samples from the machine supported the claims Dominion was making. Considering the fact that this other firm was selling its dryer, which incidentally is the most expensive part of paper machine, at a very cheap price, the Company saw that it would be a good deal to purchase the machine parts and install them with a unit of Dominion's Papriformer, which was also cheap because it was new on the market. So a Papriformer was installed at Mill B2 with the other machine parts that were purchased. Similarly, the 1975 installations were also based on a decision to make the Mill B4 a newsprint mill when the production of boxboard for intra-company use was discontinued in 1973. The result was that the mill had to be modernised, including increasing the production capacity of the machines and improving their product quality as well. So a quick decision had to be made to speed up No 2 and then No 1, paper machines.

In the same way, most of Firm C's subsequent adoptions did not follow a set-down plan but depended mostly on the exigencies of the situation. The following comments by the Project Manager elaborates this point.

> The timing of installations depends on circumstances. We do not spend money unless there is justification for it. Production and Sales people are working together. There is the knowledge of how our competitors are doing in their sales. These orientate us. We know what we are producing and if we are not doing well we have to do something about the machine. The printers always report back to us about quality ratings and they are more direct and very open in their reports. If your competitor is able to do better with a former you have to change.

Thus the 1975 Papriformer and Periformer installations at the Mill C2, for example, were motivated by the fact that the high speed newsprint production was becoming industrial standard at that time. So with the experience of the 1972 Papriformer, the company decided to move fast into installing two more machines. Similarly, the 1981-82 three Top Wire installations at the Mills C1 and C2 were due to the rapid change in the market during the late 1970s which got to a head in the early part of the 1980s (Table 6.7). As a result of oversupply of newsprint, printers became fussy about the kind of papers they wanted, and it was becoming difficult to sell newsprint produced on fourdrinier machine. In order to maintain its share of the market, the Company decided to install 3 top-wire units - 1 Dynaformer, 1 Top Flyte and 1 Bel Form on No.1 machine, Mill C1 and Nos. 2 and 5 machines, Mill C2 , respectively (Table 6.7). The 1985-86 installations at Mill C3 was necessitated by a change in ownership. The mill was purchased in 1984 and immediately had to be modernised. In particular, two of the machines were making very poor quality paper and therefore had to be modernised straight away.

Occasionally, due to unforseeable circumstances corporate plans with installations may not go ahead as planned thus affecting the timimg of installations. An example of this is the Bel Baie II which is scheduled to start up in 1990 at Mill C2. The machine was purchased in 1979. At that time the Company had no plans to install any new twin-wire machine. However, in order to spend some tax dollars which became available at that time, the machine was purchased. Later, the Company decided the machine would be installed at a new mill it was planning to build in the southern US However, the mill idea was abandoned. In 1982 it was decided that the machine be installed at Mill C2. However, due to a drop in the paper market, brought about by the recession in North America around that time, the project was again called off until it was resumed again in 1988. Thus, 10 years elapsed between the time after the machine was purchased and the time it finally got installed.

For Firm D the timing of subsequent adoption was motivated by the behaviour of the Company's competitors regarding twin-wire installations. In particular, all the competitors, had put in twin-wires in 1982. It was realised that more twin-wires were needed if the Company was going to be able to beat or meet its competitors on the market.

In the case of Firm E the 1987 installation was governed by the changing market conditions (Table 6.7). The original fourdrinier machine, which was rebuilt with the twin-wire, was installed in 1964. By the 1980s, as a result of market changes it was becoming clear that something had to be done about it. The product of the No. 3 machine, the Bel Baie II clearly indicated that the product of the twin-wire was much better than the fourdrinier. So a decision had to be made to rebuild the fourdrinier into a twin-wire machine.

Conclusion

The decision by a manufacturing firm to adopt or not adopt a given technology belongs, in the final analysis, in the managerial/corporate realm. In particular, it stems from the firm's specific situation at the time when the technology becomes available and the way the firm perceives the technology in relation to its operations and survival. With reference to the adoption of the twin-wire, the main reasons which provided the stimuli for the six firms were the need to improve product quality and increase production. These reasons had two main sources: external and internal. The external sources included the changing paper market which was brought about by increasing demand for not only paper product but also higher quality paper as a result of changing printing technology and also supplier initiatives in promoting a new technology that could meet these new paper market demands. The internal sources included innovativeness of company executives, the firm's investment climate and resources.

The stimuli generated some responses which in the main involved expansion and modernisation strategies. With its potential claim to be a better machine, the twin-wire became the focus of these strategies and associated investments a number of decisions had to be made about whether or not to adopt the twin-wire technology, whether or not to take the rebuild option and where to locate it if the technology is accepted. The six firms showed a wide range of behavioural characteristic in dealing with these decisions however, all of them eventually accepted the twin-wire technology for its product quality and speed relative to the fourdrinier, for five of the firms, and to the suction breast forming in the case of the remaining firm. Location decisions for the first adoptions were made differently by the three firms that adopted first. One used the size of plant, another used age of machine and the other used size/capacity of machine. Similarly of the late adopters, one used market consideration, another used age and the third used capacity. For subsequent adoptions both early and late adopters used the same criterion, namely the marketability of the machine's product.

While evaluation procedures differed among the six firms, and each evaluation emphasized a different factor depending upon the time and circumstances, there existed some agreements in the factors that were seen as important in all the procedures. These included machine-related factors, particularly product quality and machine quality, were on the whole predominant. Price and finance-related consideration though regarded by the firms as secondary, did become important determinants in some evaluations. Besides, there were some cases where administrative decisions had to be made.

With reference to the timing of adoptions the three 'early adopter' firms indicated supplier initiative and innovativeness of company executives as the two most important factors governing the timing of their first twin-wire installations. All three firms were approached by suppliers who had invented the machine and were finding ways to market it. These supplier moves were met with company executives who by that time foresaw the potential the technology held for the future of the industry and as a result decided to experiment with the machine. The installations by two of the firms were also motivated by the innovator and the fact that these firms were in close proximity to the innovator. In addition to these, corporate investment history and the investment climate also contributed to the timing of the first installation.

With the "late adopters", the three firms differed from from one another in the reasons why they installed their twin-wires relatively late and at the times they did. All the three firms showed that they knew about the twin-wire technology in fact about the same time as the early adopters . Thus the decision-making process of the Firm D's installation began in 1972, when Firms B and C installed their machines. However it was not until 1982 that the machine was finally installed. The reason for this was attributed to the fact that the parent company was being cautious about the technology while it was new at that time. Apart from that in 1975, the parent company installed one twin-wire tissue machine in another plant in the US and therefore the investment involved could have led to a delay in subsequent installation. In the case of Firm E, it was past investment history. The Company installed two fourdrinier machines in 1964 and 1968 respectively and did not think the market pressure was worth another investment. In the case of Firm F, the twin-wire technology did not exist until 1972 because that was the year when the first twin-wire tissue machine became commercially available. However, the incidence of market pressure was not strong enough to use the twin-wire tissue until the late 1970s. Besides it is also possible that the 1981 installation in the US affected the timing of the 1983 installation, since all major investments such as the twin-wire have to be approved by the parent in the US

With subsequent adoptions, there was not much of a difference in the timing between "early adopters" and "late adopters". In both cases, it depended on the situation on the product market and what competitors were doing. While firms had certain specific goals, they were flexible to react to any changes that might be detrimental to their situation. Thus even though firms had long-term rationalisation plans, the rapidly changing global economy made forecasting very difficult and as a result subsequent adoptions were guided by exigencies of the situation.

In conclusion, it can be seen that the adoption of the twin-wire technology by the six firms and the timing of the adoptions were largely determined by external forces and combination of favourable internal conditions of the firm. In particular these included first, the market changes demanding a new production technology; second the extent to which these changes affected the firm in relation to its production objectives, specialisations, and markets; third the firm's previous investment history and whether it had the resources to use the new technology; fourth the firm's ability to accurately forsee and interpret these developments and bring them to bear on its own situation; and fifth the length of the decision-making process. In spite of the limited number of case studies used in the discussion, it is reasonable to suggest that these factors seem to underlie such factors as possession of R&D facilities, firm size, plant size and ownership characteristics that are usually uncovered by conventional approach.

CHAPTER VII

SUMMARY AND CONCLUSIONS

The purpose of this thesis was to respond to an identified research need in technology diffusion studies within the manufacturing sector. In spite of the number studies and some of their revealing findings, recent concerns in economic geography and other related disciplines have been raised about the failure of existing studies to get to the roots of the process of technology diffusion. Subsequently, several pleas were made by a number of researchers over the past five years or so for more studies that would move towards the direction of a better understanding of the technology diffusion process. In particular, these pleas emphasized the need for stronger conceptualisation of the technology diffusion process. In response to these concerns, this thesis had two broad goals: first, to develop a framework for the study of technology diffusion within the manufacturing sector that would lead to a better understanding of the technology diffusion process and second, to apply this framework to the diffusion of the twin-wire paper machine in Canada. A new framework was then proposed and the diffusion of the twin-wire was examined within context of this framework. The main findings and conclusions of these are now discussed below.

The Framework

The thesis attempted to develop a framework which incorporated four features often ignored in previous studies industrial geography that have focussed on technology diffusion within the manufacturing sector. First, in agreement with Thomas (1985), the thesis accepted the view that the decision-making processes leading to a firm's adoption of the technologies studied need to be explicitly considered. Second, it agreed with McArthur (1987) that it is necessary to integrate an understanding of R&D processes within the technological diffusion process. Third, it recognised that the nature and characteristics of the industry needs to considered. Fourth, it was noted that, especially given interdependence and internationalisation of firms, diffusion analysis have must extend the spatial scale of reference beyond regional or national boundaries. In virtually all cases, regions or countries have been interpreted as closed systems. With these points in mind, a new framework for technology diffusion studies in the manufacturing sector was proposed.

The thrust of the framework stems from the observation that the technology diffusion pattern that is observable at any time and at any given place is the outcome of individual corporate technology decisions. The first step in an attempt to understand the process of technology diffusion therefore is to explicitly recognise and incorporate the techology choice process in the diffusion studies. As corporate decisions, technology choices are made within a broader environment or contexts. The second step then after recognising the place of technology choice is to disaggregate the idea of the 'environment' identify the contexts in which these decisions are made. The thesis identified four main contexts of technology choice, namely the industrial context, the technology context, the spatial context and the managerial context.

In the industrial context, it was recognised that industries differ in their production functions, market demand structure, production structure and opportunities to use technology-based strategies. Since technologies tend to have strong industrial focus, these variations affect firm adoptive behaviour in various industries. An understanding of the industrial context of the technology being studied is therefore necessary for a better understanding of the entire technology diffusion process.

In the technological context, the competitive situation of a new technology depends very much on the advantages it may have over other existing alternatives. In addition, the reason why the technology was developed, who developed it and where are all important to technology choice. A technology developed by in-house R&D activities will not be as freely available soon after its development as that developed by supplier R&D activities. Continued R&D activities during the course of the innovation's life cycle widen the range of choice, improve the quality of performance, reduce the risk and uncertainty element and increase the potential for the innovation's adoption even as supplier firms seek various strategies to maintain their markets. For economic and other reasons, firms may be 'nationalistic' as various countries achieve capability to develop their own versions. The technological environment, epitomised by the organisation and function of the R&D system, therefore, provides another useful context for a better understanding of technology choice.

In terms of the spatial context, this thesis argued that manufacturing firms exist in factor and product markets that can be spatially defined and spatially disaggregated into scales. Thus while markets may be *global*, labour may be *national* and raw material inputs may be *local*. Manufacturing firms therefore have to make decisions that relate to different spatial scales. A given technology may be suitable at the global level but may not be at the national or local level because of political, social and cultural differences. In addition, certain technologies tend to be resource or input-specific. The resource or input characteristics of a firm's location may therefore determine the suitability and compatibility of a given technology. Moreover, in a global industry, questions of technological choice are themselves global and relate to the firm's international competitive position.

In the final analysis, technology choice stems from corporate decision-making. The ease with which such decisions can de made, the duration, the timing and the speed all depend upon such managerial elements as corporte innovativeness, strategy, structure, R&D activities, past investment history, past innovative history, production objectives in addition other components of the industrial, technological and spatial contexts. Firms show a wide range of variation with regard to these elements and the specific time period over which the study cover. Understanding of how these elements affect technology choice behaviour of firm will therefore increase the understanding of the technology choice process. On the basis of this framework, several questions were raised and the diffusion of the twin-wire in Canada was studied.

FINDINGS

The Industrial Context And Technology Choice

The pulp and paper industry, to which the twin-wire technology belongs is not only one of the world's oldest but also one of the most capital-intensive industries. As a result of considerable existence of economies of scale, pulp and paper production units tend to be large and entail high capital cost. In general rules of technological obsolescence are therefore not stringent and technological change has been generally slow and incremental. However, the high capital cost involved also means that any changes that affect the supply price of factor inputs can substantialy raise the already high factor cost of the industry. This makes pulp and paper firm resort to several methods, including technological choices, to reduce their production cost and remain competitive.

However, with respect to technological choices, the nature and the extent of the process depends on the sector of the industry within which the firm is operating. In particular, the sectors differ in their market demand characteristics and economies of scale. In the bulk sector of newsprint and linerboard economies of scale are considerably larger than in the non-bulk and higher value-added sectors such as the printing and writing paper. Thus very large scale production is the order of the day. However, the demand conditions are such that the two product, newsprint and linerboard, have to be highly standardised. Changes in the standardised quality is dictated by the market. As a result, technology choices are not made unless market conditions indicate that such choices are safe. This also means that once market conditions demand a new technology, pulp and paper firms in the bulk sector cannot stay on for long without adopting the technology. Thus while firms are hesitant to make decisions about new technologies, once the process is initiated, and market conditions give continued support to it, the reaction of other firms can be rather swift. The situation is different in the non-bulk sector of tissue and fine paper. Economies of scale are not as high as the bulk sector because of different combinations of pulp and additives required. However, in this sector brand names, advertising and other product differentiation opportunities exist by which firms can gain competitive edge. For this reason, firms operating in the bulk sector are more sensitive to production oriented technologies while non-bulk sector firms are more sensitive to market-oriented technologies.

These also have implications for information flow. In the bulk sector, barriers to information flow about new technologies are relatively non-existent while in the non-bulk sector, new technologies are more likely to be guided as company 'trade secrets' and by patents. Thus, availability of capital and extent of market competition are more likely to influence technology choices than information flow and firm size.

In general, the Canadian pulp and paper industry shares in these characteristics. In particular, with its overwhelming strength in newsprint, most of Canadian pulp and paper firms share in the characteristics of the bulk sector. In this case, information flow is not a constraint to the adoption of the twin-wire paper machine. Market pressure, potential of production cost minimisation and compatibility of the twin-wire to the operation characteristics in the bulk sector are therefore the more important reasons for the adoption of the twin-wire paper machine in Canada.

The Technological Context And Technology Choice

The development of the twin-wire paper machine was motivated by the demand for higher quality paper and the need to increase production to meet the needs of the paper market in particular , the newsprint market. The research and development process of the technology was largely conducted by the paper machine manufacturers. Different market situations that these suppliers had to address defined certain technological trajectories within the broad paradigm of the twin-wire technology. As national capabilities of twin-wire technologies emerged the pattern of adoption also became affected even as firms became more 'nationalistic'. This had considerable impact on the timing of adoptions. With the passing of the first stage machines, competitive strategies of suppliers became more and more important as suppliers embarked on incremental technical changes and horizontal integration to gain a niche in the market. These activities increased the range of choice of the technology, the range of products to which it could be applied and greatly improved the technology's quality performance over and above the old one, namely the fourdrinier.

In Canada, these developments were of significance to the choice of the twin-wire technology. As the world's leader in newsprint production and export trade, the development of the twin-wire, primarily for newsprint was very crucial. Thus it was the first country to adopt the twin-wire technology. The development of the technology from outside the pulp and paper industry also meant that right from the beginning supplier strategy would be the driving force regarding the flow of information about the technology. Thus the machine which was first installed in Canada was developed in the US. The achievement of national capability in the early stages of the development of the twin-wire technology was also relevant for Canada in providing an opportunity for innovative Canadian firms to take an early lead in the adoption of the twin-wire technology. Finally, supplier strategies of horizontal integration and incremental technical changes provided Canadian firms the opportunity to observe the latest development in the technology in close physical proximity even at a time when Canada's twin-wire technological capability had began to decline.

The Spatial Context And Technology Choice

Within the spatial context, adoptive behaviour of pulp and paper firms at the global level seems to suggest that countries that are in close geographical proximity tend to have similar adoptive patterns. Thus the choices made by Canadian and American firms, as depicted by patterns they produced, were much more alike in terms of the number and time than those made by European firms, and vice versa. The similarity becomes even clearer with respect to specific grades. Thus firms in Finland and FRG were very much alike in their twin-wire adoptive patterns with respect to the printing and writing paper sector, while firms in Canada, and US and Japan were much more so in the newsprint sector. For the same reason, the type of machines and units adoptered also differed among countries and regions. The only exception to this case was Japan. However, the similarity that twin-wire choices in that country had with those of the US and

Canada could be attributed to similarity in industry structures of the three countries. Linking these patterns to the regionalised nature of the global paper market, the direction of paper trade and other paper trade-related matters these observations clearly reflect on the role of market competition and interdependence in shaping the technology choice process. In addition, they also reflect on the national/regional industrial structures and specialisations and point that technology choices made within national boundaries tend to be also influenced by those outside the national boundaries and particularly those who are competitors.

The overwhelming majority of Canada's twin-wires in newsprint production reflected the role of national industrial and production structure as well as corporate production specialisation in the choice of the twin-wire technology. Historically, Canada's traditional strength in the paper industry has been in the newsprint sector. Canadian pulp and paper firms are the world's biggest newsprint producers. It is therefore not surprising that the number of twin-wires adopted in the production of the other paper grades is extremely small. Considering the fact that the twin-wire technology for paper grades was developed first and foremost for the newsprint sector and was developed outside Canada, this could also be a partial explanation why Canadian firms took an early lead in the innovation and adoption of the twin-wire technology. In this case it is reasonable to suggest that had the twin-wire technology made its debut in paper grades other than newsprint, the adoptive behaviour of Canadian firms would have been different and this would have produced a different diffusion pattern.

Within Canada some statistical associations were established to the fact that most of the firms that had adopted the twin-wire technology were also large, multi-plant and had R&D facilities on site. Locations of head office were also found to be associated with adoption. In particular firms with head office locations in metropolitan areas were found to be adopters more than those with non-metropolitan locations. However, no such association was found between Canadian ownership and adoption. In addition, these characteristics did not account for regional differences. The differences that exist at the regional level reflected more on the role of regional industrial structure and specialisations. The concentration of newsprint capacity in the two provinces of Quebec and Ontario underlies why there is also the concentration of twin-wire machines in the two provinces. In addition, this pattern reflects the point made by Martin et al (1979) that the two provinces were the pioneer regions for the industry in Canada. As a result, at the time that the twin-wire machines came into being, the two regions had much older machines in need of modernisation more than in the other provinces, hence their early lead.

The Managerial Context And Technology Choice

The decision by a manufacturing firm to adopt or not adopt a given technology belongs, in the final analysis, in the managerial/corporate realm. In particular, it stems from the firm's specific situation at the time when the technology becomes available and the way the firm perceives the technology in relation to its operations and survival. With reference to the adoption of the twin-wire, the main reasons which provided the stimuli for the six firms were the need to improve product quality and increase production. These reasons had two main sources: external and internal. The external sources included the changing paper market which was brought about by increasing demand for not only paper product but also higher quality paper as a result of changing printing technology and also supplier initiatives in promoting a new technology that could meet these new paper market demands. The internal sources included innovativeness of company executives, the firm's investment climate and resources.

The stimuli generated some responses which in the main involved expansion and modernisation strategies. With its potential claim to be a better machine, the twin-wire became the focus of these strategies and associated investments a number of decisions had to be made about whether or not to adopt the twin-wire technology, whether or not to take the rebuild option and where to locate it if the technology is accepted. The six firms showed a wide range of behavioural characteristic in dealing with these decisions however, all of them eventually accepted the twin-wire technology for its product quality and speed relative to the fourdrinier, for five of the firms, and to the suction breast forming in the case of the remaining firm. Location decisions for the first adoptions were made differently by the three firms that adopted first. One used the size of plant, another used age of machine and the other used size/capacity of machine. Similarly of the late adopters, one used market consideration, another used age and the third used capacity. For subsequent adoptions both early and late adopters used the same criterion, namely the marketability of the machine's product.

While evaluation procedures differed among the six firms, and each evaluation emphasized a different factor depending upon the time and circumstances, there existed some agreements in the factors that were seen as important in all the procedures. These included machine-related factors, particularly product quality and machine quality, were on the whole predominant. Price and finance-related consideration though regarded by the firms as secondary, did become important determinants in some evaluations. Besides, there were some cases where administrative decisions had to be made.

With reference to the timing of adoptions the three 'early adopter' firms indicated supplier initiative and innovativeness of company executives as the two most important factors governing the timing of their first twin-wire installations. All three firms were approached by suppliers who had invented the machine and were finding ways to market it. These supplier moves were met with company executives who by that time foresaw the potential the technology held for the future of the industry and as a result decided to experiment with the machine. The installations by two of the firms were also motivated by the innovator and the fact that these firms were in close proximity to the innovator. In addition to these, corporate investment history and the investment climate also contributed to the timing of the first installation.

With the "late adopters", the three firms differed from one another in the reasons why they installed their twin-wires relatively late and at the times they did. All the three firms showed that they knew about the twin-wire technology in fact about the same time as the early adopters . Thus the decision-making process of the Firm D's installation began in 1972, when Firms B and C installed their machines. However it was not until 1982 that the machine was finally installed. The reason for this was attributed to the fact that the parent company was being cautious about the technology while it was new at that time. Apart from that in 1975, the parent company installed one twin-wire tissue machine in another plant in the US and therefore the investment involved could have led to a delay in subsequent installation. In the case of Firm E, it was past investment history. The Company installed two fourdrinier machines in 1964 and 1968 respectively and did not think the market pressure was worth another investment. In the case of Firm F, the twin-wire technology did not exist until 1972 because that was the year when the first twin-wire tissue machine became commercially available. However, the incidence of market pressure was not strong enough to use the twin-wire tissue until the late 1970s. Besides it is also possible that the 1981 installation in the US affected the timing of the 1983 installation, since all major investments such as the twin-wire have to be approved by the parent in the US.

With subsequent adoptions, there was not much of a difference in the timing between "early adopters" and "late adopters". In both cases, it depended on the situation on the product market and what competitors were doing. While firms had certain specific goals, they were flexible to react to any changes that might be detrimental to their situation. Thus even though firms had long-term rationalisation plans, the rapidly changing global economy made forecasting very difficult and as a result subsequent adoptions were guided by exigencies of the situation.

To sum up, it can be seen that the choice of the twin-wire technology by the six firms and the timing of the adoptions were largely determined by external forces and combination of favourable internal conditions of the firm. In particular, these included first, the market changes demanding a new production technology; second, the extent to which these changes affected the firm in relation to its production objectives, specialisations, and markets; third, the firm's previous investment history and whether it had the resources to use the new technology; fourth, the firm's ability to accurately forsee and interpret these developments and bring them to bear on its own situation; and fifth, the length of the decision-making process. The choices became possible finally because it was appropriate for the firms to do so within the industrial, technological and spatial contexts as well. These factors seem to underlie such factors as possession of R&D facilities, firm size, plant size and ownership characteristics that are usually uncovered by conventional approach.

Thus, this thesis has demonstrated that the study of technology diffusion by way of a technology choice approach has more prospects towards the understanding of the complex phenomenon of technology diffusion process than previous studies of technology diffusion in industrial geography.

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APPENDIX

FOLLOW-UP QUESTIONS FOR PULP AND PAPER MANUFACTURERS

The purpose of this exercise is to try to obtain some idea of why you install twin-wire and top-wire paper machine and what factors you take into consideration when evaluating the various options of twin-wires and top-wires you want to install. Since not all the items in the list below may apply to your various situations, only answer those that may be applicable.

For each of the items listed below circle

1 if the item was VERY IMPORTANT

2 if the item was IMPORTANT

3 if the item was SOMEWHAT IMPORTANT

4 if the item was NOT IMPORTANT

5 if the item was NOT CONSIDERED

in the decision-making process of your twin-wire/top-wire installation(s).

A. GENERAL REASONS FOR INSTALLATION

- To improve product quality 1 2 3 4 5
- To increase production 1 2 3 4 5
- To increase machine speed 1 2 3 4 5
- To maintain market 1 2 3 4 5
- To expand market 1 2 3 4 5
- To remain competitive 1 2 3 4 5
- To increase profit 1 2 3 4 5
- To reduce production cost 1 2 3 4 5
- To use the state-of-the-art technology 1 2 3 4 5
- To be ahead of competitors 1 2 3 4 5

If you were to rank the above items in order of importance how would you rank them? Please put the ranks at the left-hand side of each item, ranking the most important as 1 and proceding in that order.

B. GENERAL FACTORS IN EVALUATING OPTIONS

- Product quality 1 2 3 4 5
- Machine quality 1 2 3 4 5
- Confidence in the supplier 1 2 3 4 5
- Machine cost 1 2 3 4 5
- Technical support from supplier 1 2 3 4
- Type of product 1 2 3 4 5
- Type of furnish 1 2 3 4 5
- Company's own previous experience 1 2 3 4 5
- Other mills' experience 1 2 3 4 5
- Delivery time 1 2 3 4 5
- Personal reasons 1 2 3 4 5

If you were to rank the above items in order of importance, how would you rank them? Please put the ranks at the left hand side of the items, ranking the most important as 1 and proceding in that order.

C. PRODUCT QUALITY FACTORS

- Formation 1 2 3 4 5
- Streaking 1 2 3 4 5
- Basis weight 1 2 3 4 5
- Sheet symmetry 1 2 3 4 5
- Scott bond 1 2 3 4 5
- Retention 1 2 3 4 5
- Wire and clothing marks 1 2 3 4 5
- Pinholing 1 2 3 4 5
- Cockles 1 2 3 4 5

If you were to rank the above items in order of importance how would you rank them? Please put the ranks at the left-hand side of the items, ranking the most important as 1 and proceding in that order.

D. MACHINE QUALITY FACTORS

- Learning curve 1 2 3 4 5
- Start-ups/Shut downs 1 2 3 4 5
- Headbox operation 1 2 3 4 5
- Former operation 1 2 3 4 5
- Wires 1 2 3 4 5
- Wet end general 1 2 3 4 5

If you were to rank the above items in order of importance how would you rank them? Please put the ranks at the left-hand side of the items, ranking the most important as 1 and proceeding in that order.

E. LEARNING CURVE FACTORS

- Easiness of start-up 1 2 3 4 5
- Length of time before achieving design speed 1 2 3 4
- Length of learning curve 1 2 3 4 5
- Vendor support in learning curve period 1 2 3 4
- Manpower requirements for start-up 1 2 3 4

If you were to rank the above items in order of importance, how would you rank them? Please put the ranks at the left-hand side of the items, ranking the most important as 1 and proceding in that order.

F. START-UPS/SHUT-DOWNS

- Unique start-up procedures 1 2 3 4 5
- Number of adjustments to be made around wet end before putting the end over 1 2 3 4 5
- Unique shut-down procedures 1 2 3 4 5

If you were to rank the above items in order of importance, how would you rank them? Please put the ranks at the left-hand side of the items, ranking the most important as 1 and proceding in that order.

G. HEADBOX OPERATION FACTORS

- Type of material (steel) used in making headbox

  1 2 3 4 5

- Type of polish 1 2 3 4 5

- Temperature compensation equipment 1 2 3 4 5

- Type of controls 1 2 3 4 5

- Basis profile stability 1 2 3 4 5

- Easiness of adjusting impingement angle 1 2 3 4 5

- Effectiveness of impingement angle on formation

  1 2 3 4 5

- Headbox consistency range 1 2 3 4 5

- MD/CD Tensile Ratio 1 2 3 4 5

- Clean running 1 2 3 4 5

- Fiber orientation across the web 1 2 3 4 5

If you were to rank the above items in order of importance, how would you rank them? Please put the ranks at the left-hand side of the items, ranking the most important as 1 and proceding in that order.

H. FORMER OPERATION

- Type of material used in former elements

  1 2 3 4 5

- Type of controls 1 2 3 4 5

- Cleanliness of wire section 1 2 3 4 5

- Effect of basis weight and vacuum level changes on

  drive-load 1 2 3 4 5

If you were to rank the above items in order of importance how would you rank them? Please put the ranks at the left-hand side of the items, ranking the most important as 1 and proceding in that order.

I. WIRE FACTORS

- Normal wire life 1 2 3 4 5
- Wire tension to run 1 2 3 4 5
- Type of fabric tensioning system 1 2 3 4 5
- Effect of fabric tensions on sheet properties

  1 2 3 4 5
- Wire cleaning process 1 2 3 4 5
- Change-out time for wires 1 2 3 4 5

If you were to rank the above items in order of importance, how would you rank them? Please put the ranks at the left-hand side of the items, ranking the most important as 1 and proceding in that order.

J. WET END GENERAL

- Downtime for installation 1 2 3 4 5
- Type of stock screening 1 2 3 4 5
- Effectiveness of attenuator on pulsation 1 2 3 4 5
- Drainage split regarding both wires 1 2 3 4 5
- Dryness run after the second couch roll 1 2 3 4 5
- Behaviour of draws in press section 1 2 3 4 5
- Amount of draws in press section 1 2 3 4 5

If you were to rank the above items in order of importance, how would you rank them? Please put the ranks at the left-hand side of the items, ranking the most important as 1 and proceding in that order.

K. OTHER FACTORS

- Number of breaks per day from press section to the main

  bank dryers 1 2 3 4 5
- Primary causes of breaks 1 2 3 4 5
- Number of holes per reel 1 2 3 4 5

If you were to rank the above items in order of importance, how would you rank them? Please put the ranks at the left-hand side of the items, ranking the most important as 1 and proceding in that order.

L. ANY COMMENTS?

THANK YOU VERY MUCH FOR YOUR TIME AND PATIENCE