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TECHNOLOGY DIFFUSION AND LIFETIMES OF PAPER MACHINES

Posing the Question and Description of the Data

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ABSTRACT: This paper outlines the questions to be considered in the main research report on lifetimes of paper machines in Finland. It includes a description of the data concerning paper and board machines and used in this study. The data has been extracted from the Paper Machine Databank maintained by the Jaakko Pöyry Corporation.

The paper presents estimates of the paper and board capacity in Finland from the first half of this century until today. It demonstrates that the portion of new machines installed and rebuilds carried out by domestic suppliers has been increasing.

The paper points out two main features of development in the industry under consideration. There has been a gradual shift from installations of new machines to modernizations and rebuilds of existing ones. In addition, the lifetimes between rebuilds have clearly become shorter.

KEY WORDS: Technology diffusion, modernizations of paper machines, lifetimes of capital assets

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Contents

1. Introduction

During the latter half of the 1980s the Finnish paper industry invested heavily in new machinery and equipment. The newest technology was adopted especially in the manufacturing of coated printing and writing papers. The main emphasis was laid on the improvement of the efficiency of production processes. New production techniques were designed to be efficient also from the point of the waste water treatment and the use of energy. Old production processes were modernized and partly shut down.

During the 1980s there happened an *essential change in the investment character* of the paper industry: there was a gradual shift in emphasis from the installations of new production processes to modernizations and improvements of old ones. New investment in machinery and equipment was carried out with energy savings in mind, among other things. In order to gain economies of scale the production capacity was heavily expanded. Extensive investment in machinery laid a foundation for the introduction of process innovations. It seems probable that together with the reduction of the production cost and improvement of the efficiency, the adoption of new production technology has served as a main motive for modernizing paper machines.

Modernizations can be classified into major rebuilds and minor improvements. Major rebuilds are generally taken to mean rebuilding of machines until they are as good as new or almost new. Besides major rebuilds, this study also deals with the events of minor modernizations and the final scrapping of machines. The spells of time between any modernizations, i.e. between minor or major ones, are called waiting times or durations.

The lifetime of a paper machine is considered to be the spell of time from the original installation of the machine until its first major rebuilding, the spell from one rebuilding to the next, or the spell from the last rebuilding until the machine is finally scrapped. We can think that these lifetimes will represent so-

called economic lifetimes or service lives of capital goods. They correspond to the expected economic service lives of capital assets which are used in firms as a basis for depreciation allowances.

By examining time spells between modernizations, we can observe that these waiting times have clearly become shorter (see Figure 6, in the Appendix 1). One of the questions considered is why there has been a *shortening in time spells between modernizations*, especially in the 1980s.

The main aim of this study is, besides gaining greater insight as regards the lifetimes of paper machines, to find out what factors have affected these lifetimes. Because the lifetime is defined to end when a major modernization (or scrapping) of a machine occurs, the aim can also be expressed in the form of what factors have affected the *modernization intensities* of paper machines.

What is the theoretical framework in the investigation of modernizations and time spells between them? In this study, the points of departure are the theory of investment behaviour and, in particular, replacement theory. In addition, there is a brief examination of the diffusion theory of innovations and its connection with the theory of investment. The hypothesis is that there is a connection between the spread of certain process innovations and lifetimes until modernization.

In the empirical part of the study, the number and frequency of modernizations are considered. After that the attention turns to investigating waiting times between modernizations and the diffusion time of a central process innovation, i.e. a *twin-wire production method*. The basic question is whether the adoption of new technology has had any impact on the lifetimes of paper machines and, more generally, on the waiting times between modernizations of these capital goods. And if so, what kind of impact? What is the role of technology diffusion in explaining the shortening of waiting times or service lives? And what is the diffusion pattern like?

A separate but related question considers the significance of

demand and supply factors. To what extent are modernizations due to new *technological opportunities*, to what extent are they driven by the demand factors? Behind the technology diffusion we can bring out a close interaction between the machine suppliers and the machine adopters.

The incentive to adopt new technologies will explain only a part of the modernizations. The other factors behind the increased modernization intensity may include factors such as the shortened life-cycle of paper products, a new production strategy causing an increase in the value-added content, conversions from one paper grade to another or an increase in the capacity and speed of machines.

Behind all these actions, there have been certain economic factors, such as the availability of funds, a low real interest rate, and demand, price, and exchange rate expectations. The decline in the world market price of printing and writing papers, as well as high raw material, labour and transport costs have probably had an impact on the increase of the unit size of machines. Also a relatively low energy price has had an effect on the structure of the whole paper industry.

One of the questions to be considered is what statistical distribution could be used to describe the diffusion pattern of the twin-wire production method in papermaking and what distribution could be used for the replacement pattern of machinery and what is the connection between them.

The central claim is that the machines and equipment are, primarily, not replaced because they are worn-out or due to fears that they are going to break down, but because they are obsolete from the standpoint of technology or the production strategy. When considering production or investment strategies, we are entering into the examination of competitive strategies. Strategic factors will certainly affect *investment timing* and by that means also lifetimes of capital goods.

The lifetimes of capital goods are a key element in the compilation of capital stock series. In recent years, there has been an

extensive discussion within the OECD whether the official capital stock series can be regarded as a plausible approximation of the economically useful capital stock. Especially, the question has arisen, whether there have been sudden changes in the average lifetimes of capital goods and what are the factors which may have shortened the service lives.

Usually, an asset's economic life may be influenced by economic conditions and the rate of technical progress. An increase in the rate of technical progress, perhaps stimulated by changes in the relative prices of factor inputs, may cause the economic life of assets to end before they are physically obsolete.

There is, however, conflicting evidence concerning the extent to which assets are either retained or discarded when an economic recession or boom occurs. The common belief is that when economic conditions are favourable, assets will be used more intensively and discarded sooner. It is likely that lifetimes decrease during periods of rapid technological and economic development. Unusual technological advances may also change lifetimes drastically, and there may be trends in lifetimes.

We usually have no firm information about the lifetimes of capital goods. There exist only a few empirical studies that utilize data on equipment service lives directly. After Winfrey's (1935) pioneering work, most studies consider only the survival patterns of cars or other transport equipment (see e.g. Groes 1976).

For this study, it was possible to get an extensive amount of information on the modernizations of paper machines. This information providing a basis for the calculation of lifetimes of these machines, was obtained from the Paper Machine Databank maintained by the Jaakko Pöyry Corporation (Pöyry 1991). Due to this databank and some additional information provided by the Finnish Paper Mills' Association (Finnpap), it was possible to construct a nearly complete event history for the most of the past and present paper and board machines in Finland.

The presence of data on events over the whole life history of paper machines enables us to utilize lifetime models and the so-

called hazard function approach to analyze the occurrence of modernizations. Both the diffusion times of an innovation and the waiting times until modernization can be analyzed by using concepts and distributions of lifetime models.

Lifetime analysis and more general event history analysis has its origin in demography and biostatistics, where it is originally called survival analysis, and in the reliability theory of engineering, called reliability analysis. In economics, the approach has usually been limited to analyzing duration of unemployment, vacancies, strikes, bonds or lifetimes of firms, and is called duration analysis. The duration analysis has its roots in the theory of stochastic counting processes and martingales. A principal point in the martingale approach is its strong emphasis on accumulation of information as time goes on.

2. Characteristics of the Finnish paper industry

Finnish forest companies have undergone profound changes in the last twenty years, especially in the 1980s. The most significant changes have entailed firm acquisitions, mergers and heavy investment. Furthermore, the internationalization of forest companies has proceeded swiftly after the mid-1980s.

During recent years the emphasis of production has shifted toward products with greater value-added content. The main trend has been a shift from production of newsprint to printing and writing papers. As world market prices of printing papers have declined manufacturers have been forced to increase sharply the unit size of paper machines. Today Finland's paper and board machines are, on average, the largest in the world. The prevalence of computer aided manufacturing also ranks high internationally.

The primary strategy of the Finnish paper industry has emphasized the high value-added content incorporated within mass production. Manufacturers have sought to gain economies of scale based on *cost efficiency*. This mass production strategy has nevertheless required heavy investment and increased the debt burden of firms.

Attempts have been made in recent years to shift from the pursuit of the cost efficiency in mass production toward the increase in the flexibility of production and product differentiation.

The high number of machine rebuilds in the 1980s created a favourable basis for process innovations. Finland has indeed been able to close the technological gap vis-à-vis other countries via high investment. Finland now holds a technological lead over the main competitors especially with respect to wood-containing grades of paper. This has been facilitated by the wide availability of the spruce wood and by low energy costs but also by adoption of new technology. Advanced technology has been adopted especially in the production of coated printing paper.

The technological improvements have meant that the paper industry has become an increasingly high-tech field. Technical developments have spurred improvements in process control and feasibility of changing from one paper grade to another as well as facilitated more efficient use of raw materials and reductions in labour inputs.

Other significant reasons for investment, in addition to the adoption of new technology, include expansion or rationalization of operations, i.e. elimination of production bottlenecks in manufacturing. Most of the investment by the paper industry is, by nature, intended to rationalize production. The motives behind investment are typically a reduction in production costs and improvement in competitiveness. Investments are intended, for instance, to spur increasingly greater exploitation of raw timber and improve the reliability of processes. Furthermore, by acquiring new machines and at the same time new technology and production capacity, a manufacturer can increase its efficiency or gain market shares.

The maintenance of a manufacturer's own market position and competitive advantage can be regarded as important factors behind technological investment. The development of technology is above all else a way of improving competitiveness. Technology can affect the unit cost of products by reducing, for instance, material, energy and labour costs. Competitiveness is often based on suc-

cessful product and process innovations as well as the know-how of company personnel. During the 1980s Finnish forest companies succeeded in gaining a competitive edge by being the first to invest in high grades of printing papers just when the demand for these products was beginning to rise sharply.

The competitive situation of the forest companies has been bolstered when acquiring new technology also by their close connections with the domestic machine suppliers. In fact, the integration of the engineering industry and the wood industry has opened doors to international markets based on the reputation for competitive and quality products. From the standpoint of technology, we can even speak of an industrial network comprised of the paper and pulp industry, the paper machine industry, the process industry and process automation.

When reflecting upon the developments in paper machines after the war, we can see that the installation of large machines did not start until the 1950s. Before that the machines were slow and their capacities very low compared with the new machines. Starting in the early 1950s greater attention was focused upon rebuilds. As the investment in paper plants rose in the early 1950s, many manufacturers were faced with two possibilities, either installing new machines or rebuilding the old ones (Jokinen 1988). This period also marked the arrival of high-speed newsprint machines.

In the 1950s the renovations were carried out using primarily American or British technology, but Finnish know-how also played a role. The turn of the 1960s marked another phase of increased investment activity in the paper industry. This was spurred, for instance, by Finland's joining EFTA as an associate member in 1961 and the gradual removal of protective duties thereafter.

The next investment wave began in 1968. The 1970s subsequently witnessed the automation of production controls. The late 1980s were marked by another investment boom spurred by the strong performance of the economy. This period also saw the phasing out of older production lines.

In the 1970s the forest industry experienced a deep crisis. Propo-

sals to solve the predicament included increasing the size of production plants and modernization of the paper machines. The temporary shut-downs of machines during the slump offered a break during which there was time to carry out the installation of process computers and replacement of worn-out machines as well as improving the quality of products and implementing energy-saving measures. On the other hand, the difficulties in profitability and financing sometimes led new investment to be postponed. Moreover, maintenance and research and development investment had to be curbed.

Keeping up with the most recent developments requires continuous investment and raising of the value-added content and product improvement. The Finnish forest industry has traditionally strived to take advantage of the possibilities created by the most advanced technology (Heikkilä et al. 1981). These opportunities have been realized in the more efficient production and manufacturing processes, but at the same time they have often required heavy investment.

3. Technology diffusion and modernizations of paper machines

Technology in the production process is generally defined as a stock of knowledge which makes it possible to produce goods (Mansfield 1961). According to Layton (1974) the first distinction we have to make is between technology as artefact and technology as knowledge (see Metcalfe, Gibbons 1991). From Mansfield's pioneering work onwards empirical studies of the diffusion of new technology have been, in the main, studies of the demand for specific artefacts. From the perspective of the artefact we are in the following considering mainly the *diffusion of products and production methods*.

According to Schumpeter's (1934) well-known distinction between invention, innovation and diffusion we can define that an invention is an idea or a model concerning a new or improved device, product, process or system, which will not necessarily lead to any technical or organisational innovation. An innovation is the act

of bringing the idea or product into commercial use. Technology diffusion begins just after the phases of invention and innovation.

An innovation can be thought of as an invention after maturation into the utilizable phase. The innovation may be an adoption of a new production process or it may be a new product sold on the market. Process innovations include the adoption of new or significantly improved production methods.

It has been argued that product innovations will create new demand and process innovations will reduce production costs (see e.g. Stoneman 1983). However, technological improvements in the design of production processes can also cause totally remodelled products (*technology push effect*) and, on the other hand, a new product designing strategy will lead to a need to improve production processes (*demand pull effect*).

The technology push hypothesis of innovation is derived largely from the ideas of Schumpeter. The demand pull hypothesis is mainly derived from the work of Schmookler in the 1960s concerning the connection between investment in capital goods and patents (Schmookler 1966).

Innovations can be classified into *radical* (or major) and *incremental innovations*. A radical innovation is, for instance, an introduction of a new type of technology. According to Freeman (1991) radical innovations change the array of products and services and not just the efficiency in use of existing commodities.

The distinction between incremental innovation and *incremental improvement* to existing products or processes is sometimes difficult to specify. Neither is it always clear about where to draw a line dividing incremental improvements from the radical discontinuities, i.e. major innovations. In fact, incremental improvements continue throughout the product life. On the other hand, we can ask, whether innovations are spread out evenly over time. For instance, Schumpeter did not regard the flow of technical and organisational innovations as a smooth, continuous process.

Even though the dividing lines are sometimes difficult to draw, there really is an important difference between the introduction of new technology and the incremental improvement of existing technology. In addition, by quoting Freeman (1991) we should notice that, in general, an incremental improvement is not simply a process of technical change, but also involves managerial and organisational innovations simultaneously with the efforts to improve technology by process innovations.

The diffusion of a new technology can be defined as a process in which an innovation spreads over time from its origin to its potential users (Rogers 1983). According to Ayres (1969) "diffusion of technology is the evolutionary process of *replacement of an old technology* by a newer one for solving similar problems or accomplishing similar objectives" (see Jaakkola 1991 p. 22). This definition of the diffusion process brings us close to the replacement theory of investment.

The introduction of innovations is, to a large degree, a function of investment. However, if we are considering diffusion of technological knowledge, the acquisition of new machines is only one of the channels for the technology diffusion. Other channels include the general flow of information, education, getting licences etc. The distinction between investment and technology adoption can be made more clear by analyzing the decision to invest and the decision to adopt a new technology separately. The cost of adoption is not the same as the mere cost of purchasing.

We pointed out above that what is being diffused is not always clear. From the perspective of the artefact, what is being diffused is typically not a given innovation but rather an entire sequence of incremental post-innovation improvements (Georghiou et al. 1986). In this connection, it is also reasonable to bring out the distinction between adoption and diffusion. In the analysis of adoption one considers the decisions taken by agents (firms) to incorporate a new technology into their activities, i.e. the reasons for adoption at a particular point in time. In the analysis of diffusion one is interested in *the nature and timing of decisions* usually in relation to specified characteristics of the adopting population (Metcalfe, Gibbons 1991).

Diffusion analysis is concerned with how the economic significance of a new technology changes over time. Economic significance may be measured e.g. by the proportion of the industry's output produced with the new process. In this sense the analysis of diffusion is closely related to the *analysis of technological substitution*, in which the displacement of one technology by another is the focus of attention.

The concept of diffusion defined above is called the *overall diffusion* by Mansfield (1961) and it is the one being considered in this study. The overall diffusion rate depends on both the *rate of imitation* (inter-firm diffusion), i.e. the proportion of firms that have adopted the innovation, and the level of use within each firm (intra-firm diffusion). Most diffusion studies consider the spread of an innovation among the firms in an industry separately from the level of use within the firm.

According to Arrow (1991) the diffusion process is not just a question of copying or imitation, but a consequence of economic motivation for the acceptance of new ideas. Thus, diffusion of technological knowledge is an active choice. Also Rosenberg (1976) has pointed out that the product or process which is diffusing through a population of adopters is subject to a continuous process of improvement and modification, so that diffusion is seldom or never a simple process of replication by imitators.

What are the factors influencing the spread of technology and innovation? Why are innovations not taken up immediately by all potential users? Why are some firms or industries early adopters and some late? What is the role of producers and users of innovation during diffusion? The standard economic explanation is that the greater the potential gains in profitability, the faster the innovation will spread. But does this mean profitability for the a potential adopter or for the producer of the technology?

The importance of demand and supply phenomena is brought out most sharply when one considers profitability or relative competitive advantage as the incentive for the adoption and diffusion of a new technology. The role of demand and supply factors in technology diffusion has been analyzed, for instance, by Stoneman and Ireland

(1983) and Metcalfe (1988).

Much of the theoretical literature over technology diffusion is concerned with the *behaviour of the time-path* of the diffusion process. What time pattern will the industry's level of use follow and why? What characteristics of the firm, industry or technology will be the key determinants influencing that time pattern?

We can describe the diffusion growth curve as a spread distribution function of an innovation over time. The speed of diffusion can be defined as the time-lag from the first adoption of technology to its certain diffusion level (see Jaakkola 1991, p. 41). This concept is different from the adoption lag concerning the time-lag between the decision to adopt and the implementation of the decision.

What is the diffusion pattern of process innovations like? How does the diffusion come out? To understand the diffusion of process innovations in papermaking it is essential to investigate the makeup of the paper machine modernizations and factors affecting the timing of these modernizations. What are the factors behind these investments? To what extent do the modernizations include the adoption of new technology or high tech? What factors affect the speed of diffusion of new technology?

Because investment has very long-run effects, the adoption of new technology is evident at least in major rebuilds. In minor modernizations the concern is, for instance, of addition of drying cylinders, rebuilding of coating units and calenders, increase in speed or other improvement.

One has grown accustomed to regarding modernizations either as capacity augmentation or capacity replacement. However, on the whole they cannot be classified as clearly one or the other. They generally include both elements. The proportion of replacement varies from one modernization to the next. The acquisition of high tech systems including electronics, measurement, control and driving systems, consists mainly of replacements.

Modernizations can be seen as the realization of a certain kind of

economically necessary capital renewal process. The primary question concerning this renewal process is what is the role of *technology upgrading* in these investment events? What is the role of conversions from one paper grade to another? What part will the rationalizations play? How have the cycles in the production or the changes in price and factor inputs affected the investment?

What significance has the adoption of innovations had? It is evident that product innovations may influence a firm's sales. Sales will be increased or the product mix of the firm will be altered. Process innovations may influence the firm's production costs, the efficiency and flexibility of production. In the longer run, innovations may influence the firm's long-term overall development and profitability. They may improve the firm's *technological capabilities*. In fact, process innovations in the form of investment for rationalization is the driving force for reducing the prices of new products.

The utilization of new technology in an innovative way will produce competitive advantages compared to competitors. In previous years an innovation was designed mainly to lower labour cost. Nowadays, the advanced manufacturing technologies are designed to offer an increase in operational flexibility. Labour savings are rarely mentioned as a factor in deciding to invest in new technology (The OECD Observer 164, June/July 1990).

The paper industry's own innovation activity has first of all been directed towards the incremental process innovations and increase in cost efficiency. In the development of process technology the main emphasis has been on efforts to save wood fibre and energy. At the same time, progress in the wood and paper technology has made it possible to raise the unit size of paper and board machines. The introduction of so-called adjustable cylinders has made it possible to increase the width of the wire to as much as 10 meters. When it was no longer feasible to increase the width of the machine, the rise of the production could be achieved only by increasing the speed of the machine and by improving the efficiency. Nowadays, the design speed of paper machines has risen to as much as 1800 meters per minute.

From the information technology viewpoint, the technical change of paper machines can be divided into the following main phases. The modernizations began properly in the 1950s. In the years 1945-1955 the instrumentation technique and process indicators were developed. The first process computers were adopted in the 1960s while the main wave of computerization occurred in the beginning of the 1970s. In the 1970s analogical differential drives were replaced by electric drives. The greatest increase in the number of electric drives dates itself to the years 1969 - 1975. The maturation phase of microprocessor technology dates itself in the years 1975 - 1980. In the 1980s, the focal point shifted to the development of integrated production control systems.

Also the adoption of pick-up equipment and differential drives were of particular significance in the development of paper machines. The pick-up equipment was the first of its kind in Europe. One of the achievements of research and development was the application of ultra-sound technology to monitoring the paper-making process (Jokinen 1988).

During the 1970s, attention was focused on the improvements of the wet end of the paper machine. As a result of an extensive research and development activity in the 1970s a new type of wet end was born, the so-called Sym-Former twin-wire unit. The first twin-wire unit was installed into the United Paper Mills' Simpele mills in 1973. It was the first hybrid former in the world. In the 1980s, the so-called Sym-Flo headbox was developed. The new model was installed first in 1984.

The twin-wire idea originates from Canada. From this basic version the Valmet Corporation with Matti Kankaanpää as a main innovator developed an improved method where the top wire runs in a different way. Although the twin-wire method cannot be regarded as an entirely Finnish innovation, it can be regarded, at least to a certain extent, as a radical innovation, which has turned out to be a leading method in the papermaking. In fact, the Sym-Concept product family is one of the cornerstones of the international success of the Valmet Corporation.

The technical superiorities having affected diffusion of twin-wire

machines include such factors as the increased speed and the easier controllability of machines, the better quality of the paper manufactured (symmetry of paper faces), diminished use of energy and reduced need for space.

In the development of paper machines the most remarkable technical progress includes the increase in the speed and width of machines and the diffusion of the twin-wire method. The development of automation is evidently one factor in explaining the diffusion. The diffusion of digital drives dates itself in the same first years as the twin-wire method.

4. Lifetimes between modernizations

In this study, the main interest lies in explaining *lifetimes between modernizations*. By using lifetime models we can investigate what are the factors covarying with the expected remaining lifetime of a technical system. Lifetime models can also be used in modelling time spells between modernizations or in analyzing factors affecting diffusion times of an innovation or affecting the shape of the diffusion pattern.

How relevant is the concept of lifetimes defined above in describing the actual economic lifetimes of paper machines? The actual lifetime of an asset commonly refers to the total length of time from its initial installation to the moment when it is finally scrapped or retired. This definition is quite clear in general. If we, however, are considering, as is the case in this study, not separate pieces of equipment but the whole production process, it may be somewhat ambiguous, what do we mean by the retirement of the production process.

A paper machine is typically a production process, i.e. a composite good, which includes several phases of production and thus several components of equipment.[1] The lifetime of this kind of

[1] The paper machine consist of three sections, the wire section, the press section and the dryer section

process can be understood as a composite of the lifetimes of the component parts which have been added to or replaced in the process since its initial construction.

From a purely technical viewpoint the service life of a piece of equipment may be extended infinitely given appropriate repair and maintenance. However, from an economic viewpoint the cost of operating a given machine may become too high relative to the flow of revenues it can produce and therefore it will be discarded.

For the sake of simplicity, a production process is defined to end in the following, as in the capital stock calculations, at the moment when it is finally closed down or completely modernized. This definition makes it possible to apply an analytically useful concept of lifetimes also for a process industry.

There are usually many events in the life history of a paper machine. There are many kinds of repairs, alterations and modifications. Except for annual repairs and maintenance we call all these events modernization. The events of complete modernization are generally called major rebuilds. A major rebuild is according to our definition a modernization which ends the lifetime of the previous machine and starts a new one. It is an event which concerns mainly the wet end or wire section of the machine. As a general rule, it includes also a lot of minor modernizations.

The actual lifetimes of assets cannot be known in advance with certainty. The exact service life of a piece of equipment or the waiting time until modernization can only be known ex post - that is, after the occurrence of the event in question. It follows that lifetimes can be regarded as random variables, which depend on the decision regarding when to discard or replace an item of capital. These lifetimes typically represent the expected periods of time delineating the usage of the asset, assuming that throughout the whole period of their usage the age retirement schedule remains unchanged. This definition is fully in accordance with the traditional way of calculating people's life expectancy figures used in demography.

5. Description of the data

The data set used in this study has been collected from the Paper Machine Databank maintained by the Jaakko Pöyry Corporation. It is a longitudinal follow-up data starting from the 1880s. The data set includes information about past and present paper and board machines in Finland. This information is complemented by the data received from the Finnish Paper Mills' Association (Finnpap) and from annual reports of firms.

The data set includes the following information about the paper and board machines: company name, mill site, machine number, start-up year, modernizations and modernization years, possible year of scrapping, original builder of the machine and supplier of modernizations, forming method, wire width, design speed, basis weight range (g/m^2), total capacity and capacity increases (t/a), paper grades manufactured, wet end, press and dryer section, drive type, auxiliaries and raw materials (grounwood or pulp). The data on modernizations include a lot of technical information concerning operations performed.

Modernizations consist of, among other things, the following operations: complete rebuilds, modernizations in the wet end, in the press or dryer sections, conversions from one paper grade to another, installations of forming methods, headboxes, calenders and coaters.

The data set does not, however, include all machines or all modernizations, at least not until the 1950s. Neither does the material uniformly include classifications of modernizations into major rebuilds and smaller improvements. As a main source concerning major rebuilds the data on rebuilds compiled by Valmet Paper Machinery (Jokinen 1988) and information about these modernizations have been utilized. The main criterion was that modernizations of the forming method or the wet end were treated as major rebuilds. Also data on investment expenditure were utilized in this context if they existed.

The data on capacity utilization rate, export prices of different paper grades, factor prices (wages, energy, timber), real interest rates, exchange rates and the number of domestic patent applications concerning paper machines have been used as factors describing economic conditions.

The data set has information about 182 production processes. The life-cycle of each process consist of one or more periods according to what they have been modernized. According to the data, there were 109 paper or board machines in operation in Finland in 1992. Their combined capacity was 11 million tonnes per year.

There are in the data 174 completed time spells between major events. If we are considering all modernizations (i.e. including major rebuilds but excluding shut downs) there are 374 completed durations in the data set. These time spells are characterized by information about their average production capacity, the paper grade manufactured and the forming method of the paper web. The other properties of the machine being under consideration will usually remain unchanged from one period to the next.

By using data on capacity increases at the modernizations we can construe an estimate to the development of the Finnish paper and board capacity over this century. The information from the year 1970 onwards is based on the data received from the Central Union of the Finnish Forest Industry. The preceding estimates rest on the calculations of the author on the basis of the Paper Machine Databank. Because this data set does not include all the closed down machines, the estimates concerning the development of paper and board capacity until 1970 have been raised to the level of the year 1970.

In the Figure 1 the paper and board capacity in Finland has been divided into two parts, the capacity produced by new machines and rebuilds delivered by domestic or foreign suppliers. The majority of the paper capacity is nowadays produced by domestic machines. It is worth noticing that although the capacity is heavily increased, the number of machines has, in fact, declined since the year 1975 (Figure 2).

We can further notice that there has been a clear increase in the number of modernizations since the 1950s (Figure 3). However, modernizations are responsible for the increase in production capacity in larger quantities just in the 1980s (Figure 4). The Figure 5 demonstrates the gradual shift from the installations of new machines to modernizations and improvements of old ones. The Figure 6 in the Appendix 1 brings out the shortening in time spells between modernizations.

Figure 1.
The Paper and Board Capacity in Finland
Million tonnes

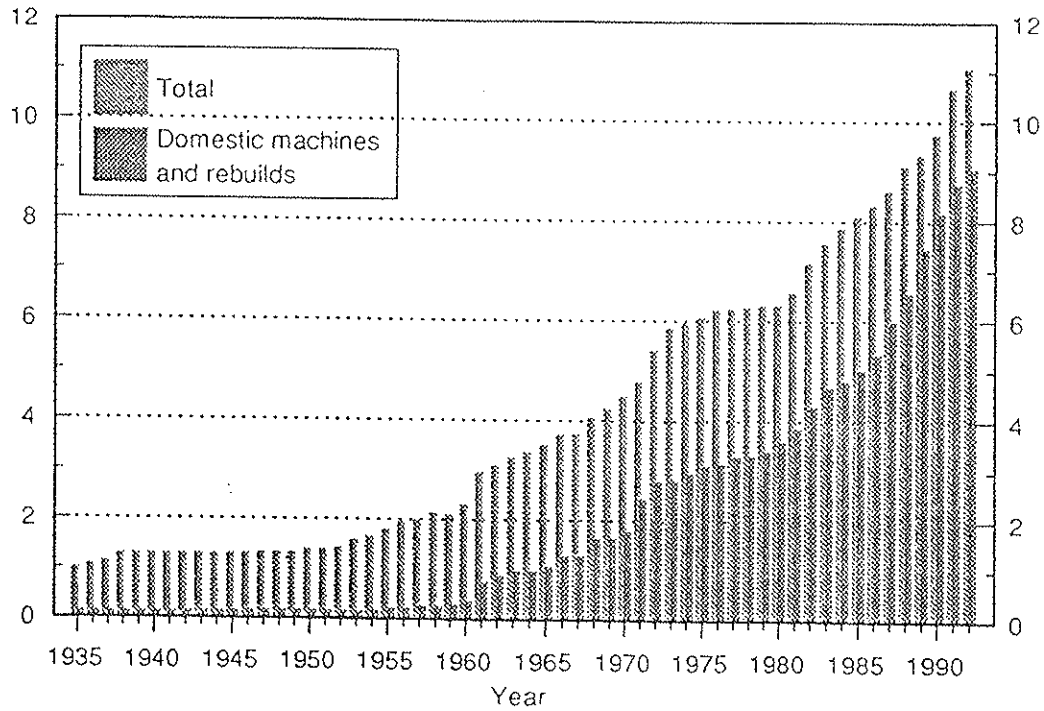
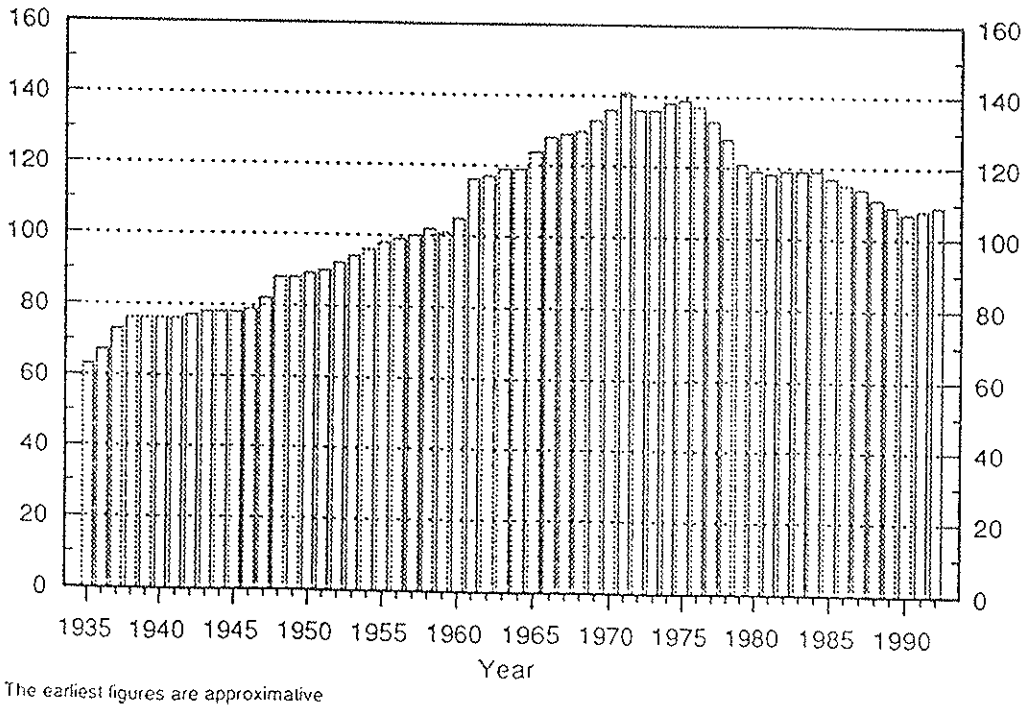


Figure 2.
The Number of Paper and Board Machines in Finland



The earliest figures are approximative

Figure 3.
The Number of Modernizations
of the Paper and Board Machines

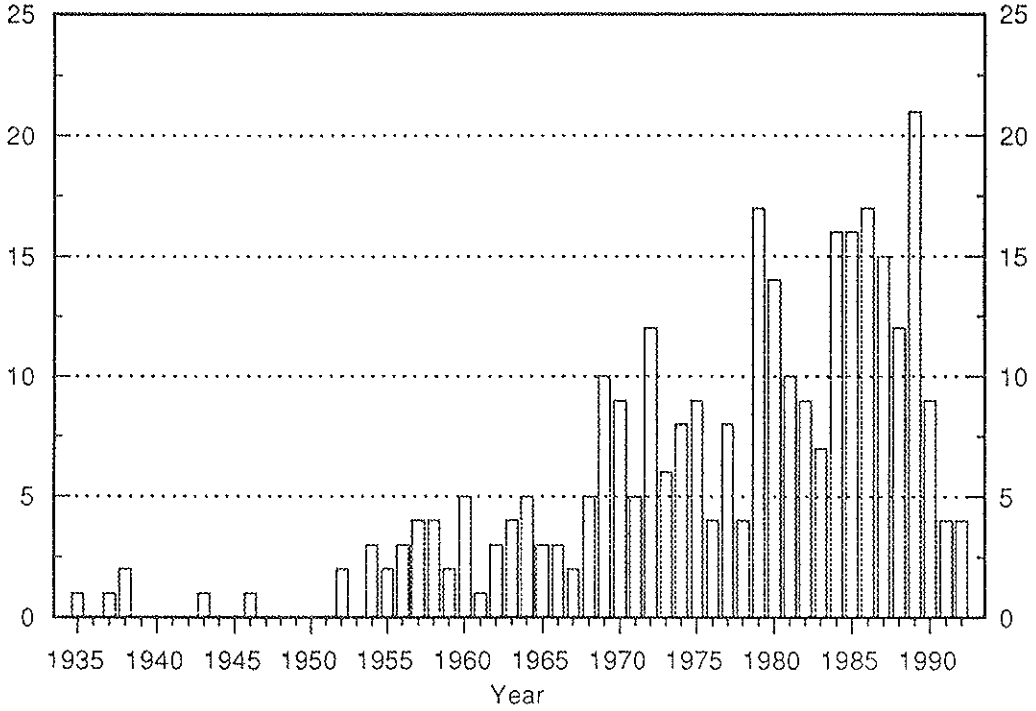


Figure 4.
The Increase in the Paper and Board Capacity
Due to Modernizations
Thousand tonnes

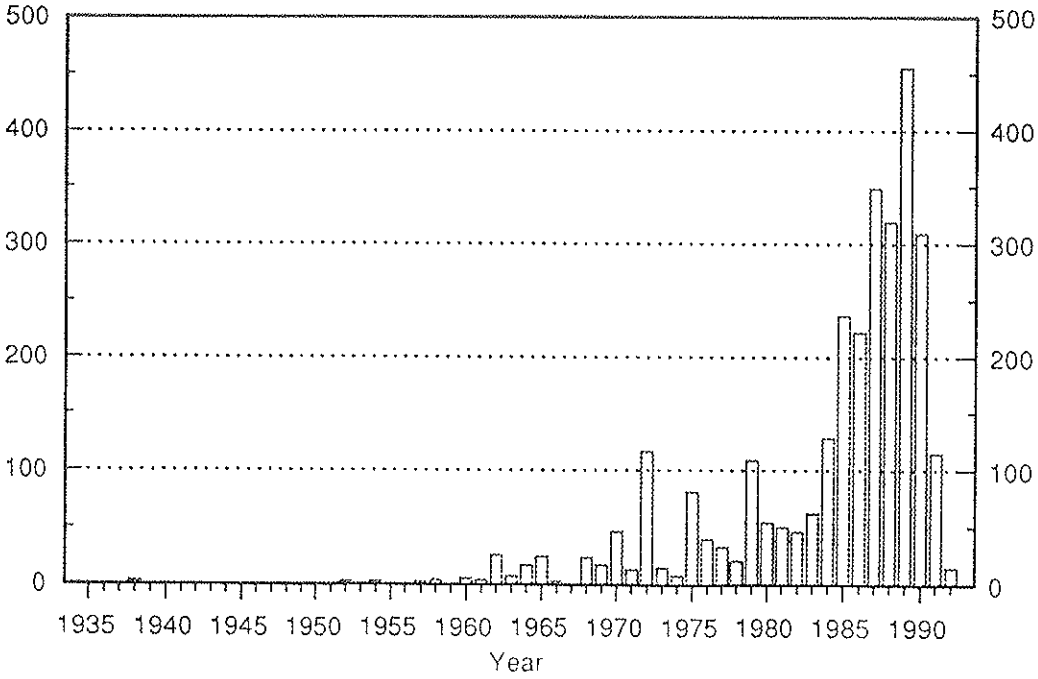
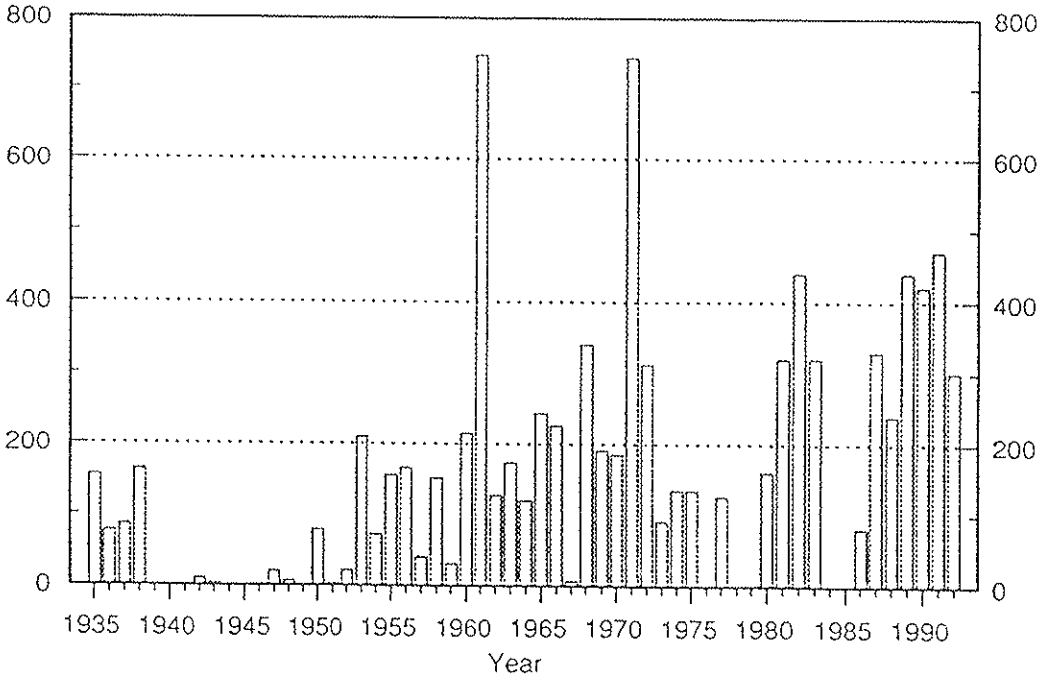


Figure 5.
The Increase in the Paper and Board Capacity
Due to Installations of New Machines
Thousand tonnes



The strong investment activity in the 1980s has led to widespread introduction of modern technology in the Finnish paper industry. The data concerning the adoption of the twin-wire forming method (Sym-Former, Speed-Former, Tamformer or Ahlformer top wire units) has been summarized in the Appendix 2.

Literature

Abel, A.B. (1979), *Investment and The Value of Capital*, Garland, New York.

Aitkin, M., Anderson, D., Francis, B., Hinde, J, (1989), *Statistical Modelling in GLIM*, Oxford Statistical Series, Oxford.

Andersen, P.K., Borgan, O. (1985), Counting Process Models for Life-history Data: A Review, *Scandinavian Journal of Statistics* 12, 97-158.

Arjas, E. (1989), Survival Models and Martingale Dynamics, *Scandinavian Journal of Statistics* 16, 177-225.

Arrow, K.J. (1991), The Dynamics of Technological Change, In: OECD (1991b).

Ayres, R.U. (1969), *Technological Forecasting and Long-Range Forecasting*, McGraw-Hill Book Company, New York.

Balcer, Y., Lippman, S.A. (1984), Technological Expectations and Adoption of Improved Technology, *Journal of Economic Theory*, 34, 292-318.

Barlow, R.E., Proschan, F. (1975), *Statistical Theory of Reliability and Life Testing*, Holt, Rinehart & Winston, New York.

Bass F.M. (1969), A New Product Growth Model for Consumer Durables, *Management Science* 15, January 1969, pp. 215-227.

Blackman A.W. (1972), A Mathematical Model for Trend Forecasts, In: *Technological Forecasting and Social Change* 3, pp. 441-452.

Bergström, W. (1976), Approaches to The Theory of Capital, *The Scandinavian Journal of Economics* 78, pp. 437-456.

Berndt, E.R., Wood, D.O. (1986), Energy Price Shocks and Productivity Growth in US and UK Manufacturing, *Oxford Review of Economic Policy*, Vol.2, No.3.

Bitros, G.C., Kelejian, H.H. (1974), On the Variability of the Replacement Investment Capital Stock Ratio: Some Evidence from Capital Scrappage, *The Review of Economics and Statistics*, LVI (3)

Björn, E. (1989), *Taxation, Technology and the User Cost of Capital*, North Holland, Amsterdam.

Blades, D. (1989), Capital Measurement in the OECD Countries: An Overview, International Seminar on Science, Technology and Economic Growth, OECD, DSTI/SPR/89.7, Paris.

Cederblad, C.O. (1971), Realkapital och avskrivning, Begreppsanalys, Mätmöjligheter i Sverige, *Urval Nummer 4*, Stockholm.

Chenery, H.B. (1952), Overcapacity and The Acceleration Principle, *Econometrica* 20, January, pp. 1-28.

Chhikara, R.S., Folks, J.L. (1989), *The Inverse Gaussian Distribution, Theory, Methodology, and Applications*, Marcel Dekker Inc, New York and Basel.

Clark, J.M. (1917), Business Acceleration and The Law of Demand, A Technical Factor in Economic Cycles, *Journal of Political Economy*, 25, pp. 217-235.

Clark, P.K. (1979), Investments in The 1970s, Theory, Performance and Prediction. *Brookings Paper on Economic Activity* 1979:1. pp. 73-124.

Coen, R.M. (1975), Investment Behavior, The Measurement of Depreciation and Tax Policy, *American Economic Review* 65, March 1975.

Cohen, W.M. and Levin, R.C. (1989), Empirical Studies of Innovation and Market Structure, in: Schmalensee, R. and Willig, R.D. (eds.), *Handbook of Industrial Organization*, Volume II. Amsterdam/New York/Oxford/Tokyo: North Holland, p. 1059-1107.

Coleman J.S. (1964), *Introduction to Mathematical Sociology*, Free Press, New York.

Cox, D.R.,Oakes, D. (1984), *Analysis of Survival Data*, London, Chapman and Hall.

David, P.A. (1969), A Contribution to the Theory of Distribution, Research Memorandum no. 71, Research Center in Economic Growth, Stanford University.

Davies, S.(1979), *The Diffusion of Process Innovations*, Cambridge University Press, Cambridge, New York.

Eisner, R., Strotz, H. (1963), Determinants of Business Investment, in: Commission on Money and Credit, Impacts on Monetary Policy, Prentice-Hall, Englewood Cliffs, NJ, 60-138.

Eisner, R, Nadiri, M.I. (1968), Investment Behaviour and Neoclassical Theory, *Review of Economics and Statistics*, 50.

EUROSTAT (1991), Stocks of Fixed Assets in Industry in the Community Member States: Toward Greater Comparability, *Studies of National Accounts*-No 2.

Evans, M.K (1969), *Macroeconomic Activity, Theory, Forecasting and Prediction*, Harper and Row, New York.

Feldstein, M.S., Foot, D.K. (1971), The Other Half of Gross Investment: Replacement and Modernization Expenditures, *The Review of Economics and Statistics*, LIII (1), 49-58.

Feldstein, M.S., Rothschild, M. (1972), Towards an Economic Theory of Replacement, *Discussion Paper no. 249*, Harvard Inst. Econ.

Freeman, C. (1991), The Nature of Innovation of the Productive System, In *OECD* (1991b).

Freeman C., Clark, J., Soete, L.L.G. (1982), *Unemployment and Technical Innovation: A Study of Long Waves in Economic Development*, Frances Pinter, London.

Freeman C., Perez C. (1988), Structural Crises of Adjustment, Business Cycles and Investment Behaviour, In Dosi et al.(eds), *Technical Change and Economic Theory*, Printer Publishers, London 1988.

Fisher J.C., Pry R.H. (1972), A Simple Substitution Model of Technological Change, In: *Technological Forecasting and Social Change* 3. pp. 75-78.

Georghiou, L. et al. (1986), *Post Innovation Performance*, Macmillan, London.

Gomulka, S. (1976), Do New Factors Embody Best-practice Technology? New Evidence, *Economic Journal* 86, 859-863.

Groes, N. (1976), Measurement of Capital in Danmark, *The Review of Income and Wealth*, series 22, No. 3, 1976.

Hall, R.E. (1968), Technical Change and Capital from the Point of the Dual, *Review of Economic Studies*, 35, p.35-46.

Hansson, Bengt (1989), Construction of Swedish Capital Stocks, 1963-87: An Application of the Hulten-Wykoff Studies, *Economic Studies* 1989:2.

Heikkilä, T. et al. (1981), Metsäteollisuuden automaatio. Automaatiopäivät 1981.

Helliwell, J. (1976) (ed.), *Aggregate Investment*, Penguin, Harmonsworth.

Hibbert, J., Griffin, T.J., Walker R.L.,(1977), Development of Estimates of the Stock of Fixed Capital in the United Kingdom, *The Review of Income and Wealth*, June 1977.

Hulten, C.R, Wykoff, F.C. (1981), The Estimation of Economic Depreciation Using Vintage Asset Prices, An Application of the Box-Cox Power Transformation, *Journal of Econometrics* 15,367-396, 1981.

Hölttä, R. (1989), Multidimensional diffusion of innovation, *Acta Academiae Oeconomicae Helsingiensis*, Series A:66, Helsinki, The Helsinki School of Economics and Business Administration.

Jaakkola, H. (1991), *An Analysis of the Diffusion of Information Technology in Finnish Industry*, Tampere University of Technology, Publications 70 (in Finnish, Summary in English).

Jaffey, M. (1990), The Measurement of Capital Through a Fixed Asset Accounting Simulation Model (FAASM), *Review of Income and Wealth*, series 36, Number 1, March 1990.

Jensen, R. (1982), Adooption and Diffusion of An Innovation of Uncertain Profitability, *Journal of Economic Theory* 27, 182-193.

Jensen, R. (1992), Innovation Adoption and Welfare Under Uncertainty, *The Journal of Industrial Economics*, Vol. XL,p.173-180.

Jokinen, J. (1988), *From Field-Gun to Paper Machine*, Valmet Paper Machinery Inc. Gummerus Oy, Jyväskylä.

Jorgenson, D.W. (1963), Capital Theory and Investment Behaviour, *American Economic Review*, 53, 247-259.

Jorgenson, D.W. (1967), The Determinants of Investment Behaviour, National Bureau of Economic Research.

Jorgenson, D.W. (1974), The Economic Theory of Replacement and Depreciation, in W. Sellekaerts (ed.) *Econometrics and Economic Theory*, New York.

Jorgenson, D.W., McCall, J.J., Radner, R. (1967), *Optimal Replacement Policy*, North Holland, Amsterdam.

Kalbfleisch, J.D.,Prentice, R.L.(1980), *The Statistical Analysis of Failure Time Data*, New York, Wiley.

Keese, M., Salou, G., Richardson, P. (1991), The Measurement of Output and Factors of Production for The Business Sector in OECD Countries, *Working Paper* No. 99, OCDE/GD(91)92, OECD, Paris.

Kiefer, N. (1988), Economic Duration Data and Hazard Functions, *Journal of Economic Literature*, Vol XXVI, p. 646-679.

King, M.A. (1972), Taxation and Investment Incentives in a Vintage Investment Model, *Journal of Public Economics* 1, pp. 121-148.

Koizumi, S. (1969), Technical Progress and Investment, *International Economic Review*, 10, 68-81.

Koumanakos, P., Hwang, J.C. (1988), The Forms and Rates of Economic Depreciation, The Canadian Experience, *Statistics Canada* 1988.

Kriström, B. (1990), The Classical Theories of Investment and the Forest Sector; Some Results, *Arbetsrapport*, Sveriges lantbruksuniversitet, Umeå.

Lakhani H. (1975), Diffusion of Environment-Saving Technological Change - A Petroleum Refining Case Study, In: *Technological Forecasting and Social Change* 7, pp. 33-35.

Lavaraj U.A., Gore A.P. (1990), On Interpreting Probability Distributions Fitted to Times of First Adoption, In: *Technological Forecasting and Social Change* 37, pp. 355-370.

Lawless, J.F. (1982), *Statistical Models and Methods for Lifetime Data*, John Wiley & Sons, USA.

Layton, E (1974), Technology as Knowledge, In: *Technology and Culture*, Vol. 15.

Lehtoranta, O. (1991), Estimation des Flux et des Stocks de Capital Fixe: Definitions et Methodologie utilisees en Finlande, ESD/STAT/SNA/RD(91)4, *OECD*, Paris.

Lehtoranta, O. (1992), Estimating Stocks of Fixed Capital: Methods used in Different Countries, *Discussion Papers* no. 395, ETLA.

Lützel, H. (1977), Estimates of Capital Stock by Industries in the Federal Republic of Germany, *The Review of Income and Wealth*, March 1977.

McCardle, K.F. (1985), Information Acquisition and the Adoption of New Technology, *Management Science* 31: 1372-1389.

Mansfield, E. (1961), Technical Change and the Rate of Imitation, *Econometrica* 1961.

Mansfield, E. (1968a), *Industrial Research and Technological Innovation*, W.W. Norton, New York.

Mansfield, E. (1968b), *The Economics of Technological Change*, W.W. Norton, New York.

Mansfield, E. (1980), Basic research and productivity increase, *American Economic Review*, Vol. 70, No. 5, December, p. 863-873.

McHugh, R., Lane, J. (1987), The Role of Embodied Technological Change in the Decline of Labor Productivity, *Southern Economic Journal* 1987.

Metcalfe, J.S. (1981), Impulse and Diffusion in the Study of Technical Change, *Futures*, 5, 347-359.

Metcalfe, J.S. (1988), The Diffusion of Innovation: An Interpretative Survey, in: Dosi,G., Freeman, C., Nelson, R., Silverberg, G. and Soete, L. (eds.), *Technical Change and Economic Theory*. London and New York: Printer Publishers, p. 560-589.

Metcalfe, J.S., Gibbons, M. (1991), The Diffusion of the New Technologies, A Condition for Renewed Economic Growth, In *OECD* (1991b).

Miller, E. (1990), Can a Perpetual Inventory Capital Stock be Used for Production Function Parameter Estimation? *Review of Income and Wealth*, Series 36, Number 1, March 1990.

Nickell, S.J. (1978), *The Investment Decisions of Firms*, Cambridge University Press, Oxford.

OECD (1988a), Capital Stock Estimates, R&D and Total Factor Productive in a Vintage Model Framework, DSTI/IND9/88.12, *OECD*, Paris.

OECD (1988b), Capital Stock Statistics: Recent Developments, Meeting of National Accounts Experts 9-11 May 1988, DES/NI/88.6, *OECD*, Paris.

OECD (1988c), The Measurement of High Technology, Existing Methods and Possible Improvements, DSTI/IP/88.43, *OECD*, Paris.

OECD (1989), Reliability of Service Life Assumptions Used in Measuring Gross Capital Stocks, Meeting of National Accounts Experts 12-14 June 1989, DES/NI/89.6, *OECD*, Paris.

OECD (1990a), New Measures of Fixed Capital Flows and Stocks, Canada, Prepared by Statistics Canada, Meeting of National Accounts Experts 3-6 July 1990, *OECD*, Paris.

OECD (1991a), Capital Goods: Stocks, Ages and Lifetimes, Note prepared by E.H. Smeets, Netherlands Central Bureau of Statistics, Meeting of National Accounts Experts, ESD/STAT/SNA/RD(91)11, *OECD*, Paris.

OECD (1991b), Technology and Productivity, The Challenge for Economic Policy, *OECD*, Paris.

Olson J., Seungmook C., (1985) A Product Diffusion Model Incorporating Repeat Purchases, In: *Technological Forecasting and Social Change* 27, p. 385-397.

Pöyry (1991), Existing and Shut Down Paper Machines in Finland, A Printing List Prepared for ETLA (The Research Institute of the Finnish Economy), The Jaakko Pöyry Corp. 29.8.1991 Vantaa.

Ray G. (1969), The Diffusion of New Technology, *National Institute Economical Review* 48.

Reinganum, J.F. (1981), On the Diffusion of New Technology: A Game Theoretic Approach, *Review of Economic Studies* 48, 395-405

Reinganum, J.F. (1989), The Timing of Innovation: Research, Development, and Diffusion, in Schmalensee, R. and Willig, R. (eds.), *Handbook of Industrial Organization*, North Holland, New York.

Rosenberg, N. (1976), *Perspectives on Technology*, Cambridge University press.

Rogers, E.M. (1983), *Diffusion of Innovations*, MacMillan Co., New York.

Rymes, T.K. (1971), *On Concepts of Capital and Technical Change*, Cambridge University Press, Cambridge.

Sahal, D. (1981), *Patterns of Technological Innovation*, Addison-Wesley Publishing Co., Reading, Mass.

Salter, W.E.G. (1966), *Productivity and Technical Change*, Cambridge University Press.

Schmookler, J. (1966), *Invention and Economic Growth*, Harvard University Press.

Schramm, R. (1972), Neoclassical Investment Models and French Private Manufacturing Investment, *American Economic Review*, 62, 553-563.

Schumpeter, J.A. (1934), *The Theory of Economic Development*, Harvard University Press, Cambridge.

Sharif M.N., Islam M.N. (1980), The Weibull Distribution as a General Model for Forecasting Technological Change, In: *Technological Forecasting and Social Change* 18, pp. 247-256.

Spence, A.M. (1979), Investment Strategy and Growth in a New Market, *Bell Journal of Economics*, 10, 1-19.

Stier J.C. (1983), Technological Substitution in the United States Pulp and Paper Industry: The Sulfate Pulping Process, In: *Technological Forecasting and Social Change* 23, p. 237-245.

Stoneman, P. (1983), *The Economic Analysis of Technological Change*, Oxford University Press, London.

Stoneman, P., Ireland, N.J. (1983), The Role of Supply Factors in the Diffusion of New Process Technology, *Economic Journal Conference Papers*, 93, pp. 65-77.

Tengblad, Å., Westerlund, N. (1976), Capital Stock and Capital Consumption Estimates by Industries in the Swedish National Accounts, *Review of Income and Wealth*, Series 22, No. 4.

Tirole, J. (1989), *The Theory of Industrial Organization*, Massachusetts Institute of Technology (MIT), London.

Thirtle, C.G. and Ruttan, V.W. (1987), The role of demand and supply in the generation and diffusion of technical change. *Fundamentals of Pure and Applied Economics*, Vol. 21. Chur/London/Paris/New York: Harwood Academic Publishers.

Usher, D. (1976), *The Measurement of Capital*, The University of Chicago Press, Chicago 1976.

van Duijn, J.J. (1983), *The Long Wave in Economic Life*, George Allen & Unwin, London, Boston.

van Zon, A. (1989), Vintage Capital and the Measurement of Technical Progress, DSTI/SPR/89.7 *OECD*, Paris.

Wadhwani, S., Wall M. (1986), The UK Capital Stock - New Estimates of Premature Scrapping, *Oxford Review of Economic Policy*, Vol 2, No. 3, Autumn 1986.

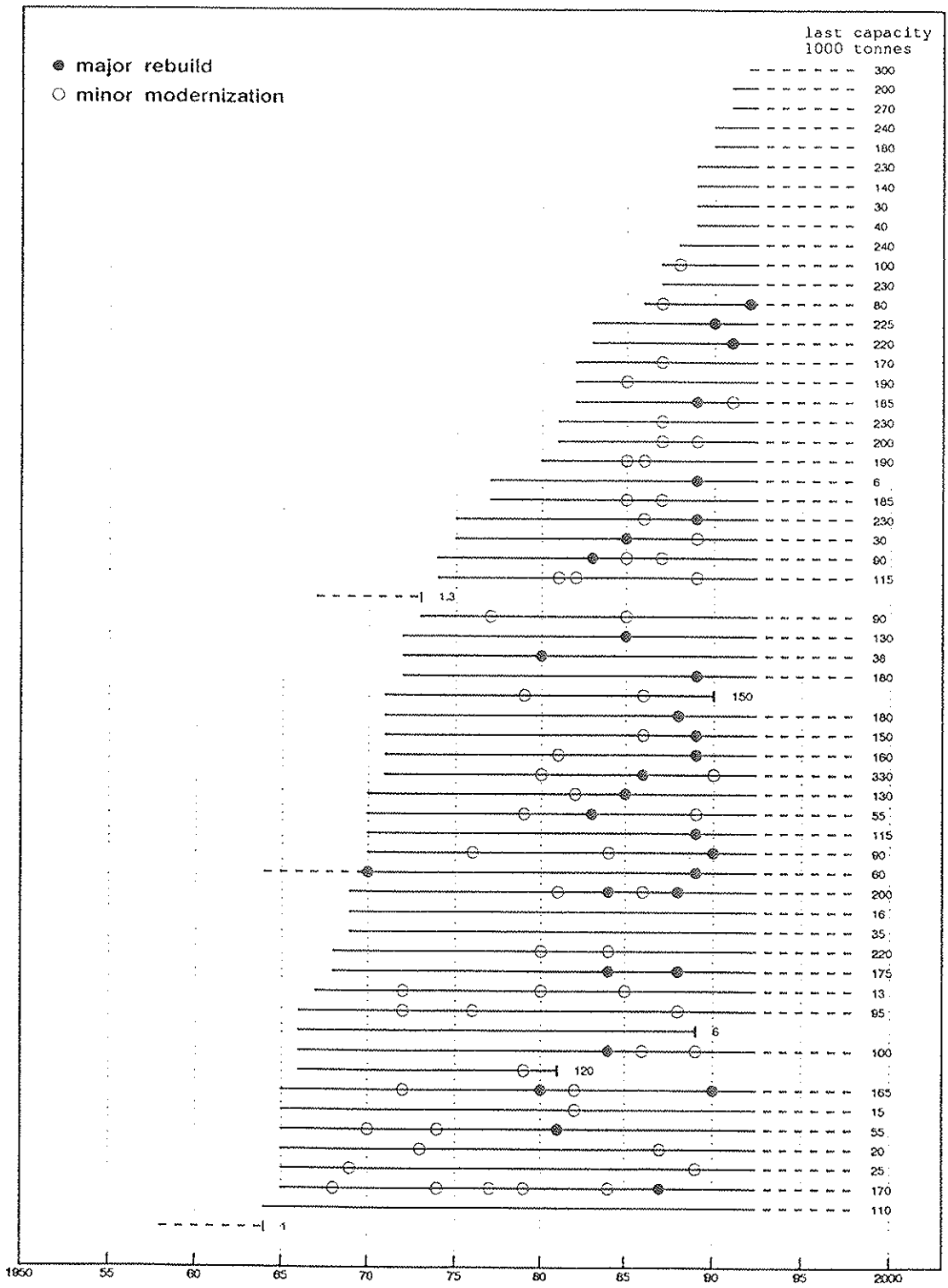
Ward, M. (1976), The Measurement of Capital, The Methodology of Capital Stock Estimates in OECD Countries, *OECD*, Paris.

Winfrey, R. (1935), Statistical Analysis of Industrial Property Retirements, Iowa Engineering Experiment Station, *Bulletin* 125, Iowa.

Wyatt, G. (1983), Multifactor Productivity Change in Finnish and Swedish Industries, 1960 to 1980, ETLA B38, Helsinki.

Appendix 1.

Figure 6. Modernizations of the paper and board machines installed after 1960



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Appendix 2. The adopters of the twin-wire forming method in Finland

Year	Mill site and company	
1973	Simpele	The United Paper Mills
1977	Varkaus	Enso-Gutzeit Oy
1978	Voikkaa	Kymmene Oy
1980	Nokia	Nokia Paper Oy
1980	Rauma	The United Paper Mills
1981	Jämsänkoski	The United Paper Mills
1981	Kotka	Enso-Gutzeit Oy
1982	Kajaani	The United Paper Mills
1982	Kaukopää	Enso-Gutzeit Oy
1982	Kirkniemi	Metsä-Serla Oy
1983	Anjala	Tampella Oy
1983	Jämsänkoski	The United Paper Mills
1983	Kemi	Veitsiluoto Oy
1983	Kuusankoski	Kymmene Oy
1984	Kemi	Veitsiluoto Oy
1984	Kyröskoski	Kyrö Oy
1984	Rauma	The United Paper Mills
1984	Voikkaa	Kymmene Oy
1985	Kemi	Veitsiluoto Oy
1985	Varkaus	Enso-Gutzeit Oy
1986	Kaipola	The United Paper Mills
1987	Kaipola	The United Paper Mills
1987	Äänekoski	Metsä-Serla Oy
1988	Kajaani	The United Paper Mills
1988	Kuusankoski	Kymmene Oy
1989	Anjala	Tampella Oy
1989	Heinola	Tampella Oy
1989	Kaipola	The United Paper Mills
1989	Kajaani	The United Paper Mills
1989	Kuusankoski	Kymmene Oy
1989	Myllykoski	Myllykoski Oy
1989	Summa	Enso-Gutzeit Oy
1990	Rauma	The United Paper Mills
1991	Oulu	Veitsiluoto Oy
1992	Jämsänkoski	The United Paper Mills

Source: The Paper Machine Databank

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