ACTA FORESTALIA FENNICA

180

PRODUCTIVITY DIFFERENTIALS IN THE FINNISH FOREST INDUSTRIES

TUOTTAVUUDEN VAIHTELU SUOMEN METSÄTEOLLISUUDESSA

Markku Simula

SUOMEN METSÄTIETEELLINEN SEURA 1983

Suomen Metsätieteellisen Seuran julkaisusarjat

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Publications of the Society of Forestry in Finland

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Seloste

TUOTTAVUUDEN VAIHTELU SUOMEN METSÄTEOLLISUUDESSA

HELSINKI 1983

SIMULA, M. 1983. Productivity Differentials in the Finnish Forest Industries. Seloste: Tuottavuuden vaihtelu Suomen metsäteollisuudessa. Acta For. Fenn. 180: 1–67.

International comparisons have revealed that the Finnish forest industries have good possibilities to improve their competitiveness in the world markets through productivity increase at branch and plant level. This requires the search for appropriate comprehensive productivity indicators and the analysis of factors underlying productivity variation, which are the main objectives of this study. The data are based on the information on individual plants in 1974, obtained from the files of Industrial Statistics in the Central Statistical Office in Finland.

The study uses neoclassical average production functions as the starting point and the theory is expanded to cover factors underlying productivity variation when measured with regard to labour, capital, materials input, and total factor input. For the measurement of the latter an index formula is suggested which would not necessarily incorporate neoclassical assumptions as they cannot be assumed valid in the Finnish forest industries. The estimation results of average production functions suggest increasing rate of returns in sawmilling but in pulp and paper production evidence remains inconclusive. The elasticity of substitution is unlikely to be constant and the non-homotheticity assumption cannot be rejected.

The productivity variation is, in general, best explained by a relatively simple model with capital-labour ratio, plant size and output quality as explanatory factors. Further trials with input quality, input price ratio, process characteristics, and the rate of capacity utilization improved the models only marginally in most cases, which may have been partly due to the failure to measure the variables successfully.

The cross-section results are compared with those of an earlier time-series study. The estimation results of average production functions yield somewhat different information in the long and short run. Both cross-section and time-series productivity models illustrate the importance of output level in total productivity.

Kansainväliset vertailut ovat osoittaneet, että Suomen metsäteollisuudella on hyvät mahdollisuudet parantaa kansainvälistä kilpailukykyään kohottamalla tuottavuutta toimialan ja tuotantoyksikön tasolla. Tällöin tarvitaan kokonaisvaltaisia tuottavuusmittareita sekä tuottavuuden vaihtelua selittävien tekijöiden analyysia. Ne ovat tämän tutkimuksen tärkeimpinä kohteina. Tutkimusaineisto perustuu Tilastokeskuksen teollisuustilaston perusaineistoon yksittäisistä tuotantoyksiköistä vuonna 1974.

Tutkimuksen lähtökohtana ovat keskimääräiset uusklassiset tuotantofunktiot. Teoria laajennetaan käsittämään myös tuottavuuden vaihtelun taustana olevat tekijät, kun mittaus on suoritettu työn, pääoman, materiaalipanoksen ja kokonaispanoksen suhteen. Jälkimmäisen mittaamista varten esitetään indeksikaava, joka ei välttämättä sisällä uusklassisia oletuksia, koska niiden ei voida olettaa pitävän paikkaansa Suomen metsäteollisuudessa.

Keskimääräisten tuotantofunktioiden estimointitulosten perusteella tuottojen aste näyttäisi olevan kohoava sahateollisuudessa, kun taas massan ja paperin tuotannon osalta päätelmiä ei voida tehdä. Korvausjousto ei välttämättä ole vakio ja epähomoteettisuusoletusta ei voida hylätä.

Tuottavuuden vaihtelua selittää yleensä parhaiten verraten yksinkertainen malli, jossa pääoma-työpanossuhde, tehdaskoko ja tuotannon laatu ovat selittävinä muuttujina. Mallit paranevat yleensä vain marginaalisesti, kun niihin sisällytetään panosten laatu, panosten hintasuhteet, prosessin erityispiirteet ja kapasiteetin käyttöaste, mikä voidaan osittain tulkita osoituksena siitä, ettei näiden muuttujien mittaus ole aineiston perusteella onnistunut.

Poikkileikkausanalyysin tuloksia verrataan aikaisemmin suoritettuun aikasarjatutkimukseen. Keskimääräisten tuotantofunktioiden estimointitulokset antavat jonkin verran erisisältöistä informaatiota tuotantosuhteista pitkällä ja lyhyellä aikavälillä. Sekä poikkileikkaus- että aikasarjamallit osoittavat tuotannon tason keskeisen merkityksen kokonaistuottavuuden muodostumisessa.

ODC 791+792+796

ISBN 951-651-055-8

Arvi A. Karisto Oy:n kirjapaino
Hämeenlinna 1983

PREFACE

The topic of this study was initiated by Dr. Risto Eklund who in 1977 foresaw the need for a theoretical analysis of productivity in the Finnish forest industries. This report presents the cross-section results of the second stage of the study, while the first study stage covered time-series analyses of productivity change in 1954–1974.

The work has been supervised by Professor Päiviö Riihinen, who has contributed decisively to the completion of the study. Valuable advice and support were received from Dr. Leo Ahonen, Dr. Veli-Pekka Järveläinen, Professor Matti Keltikangas, Dr. Olli Saastamoinen, and in particular Mr. Ilpo Tikkanen, M.Sc.

The preparation and preliminary analysis of the statistical data were carried out by Mr. Eero Ylätalo, M.Sc. and Mr. Jorma Salo has done all the data processing and programming.

English language was checked by Mr. Mark Werren. Various versions of the manuscript were typed by Mrs. Nicole Roux-Simula.

During the earlier stages of the study financial support was received from the Foundation for Research on Natural Resources in Finland and the Society of Forestry in Finland.

I whish to express my sincere gratitude to all those who have been involved in and contributed to this study.

Helsinki, October 1982

Markku Simula

LIST OF SYMBOLS

A, a, b, c, d	parameters
C	capacity
D	dummy variable
dX, dY	derivative
F	F-value
f	function
g	price of capital input
h	returns to scale
K	capital input (capital stock)
K/L	capital-labour ratio
K_q	quality of capital input
K_U	capital stock adjusted by the rate of capacity utilization
L	labour input (number of employees)
L_H	number of employee hours
L/M	labour-materials ratio
L_S	share of salaried personnel in the total number of employees
L_T	percentage of technical staff in the number of workers
L_U	average hours per employee per year
L_W	share of the hours of production workers in the total hours of all workers
ln	natural logarithm
M	materials input
M_V	volume of wood raw material used
n	number of observations
p	price (price of output)
Q	output
q	output quality
Q_F	physical output of main products
Q_G	gross value of output
Q_N	net output
Q_V	value added
R^2	multiple correlation coefficient
$\bar{R}^2$	adjusted multiple correlation coefficient
r'	Spearman's correlation coefficient
r^2	regression coefficient
S_L	income share of labour input
S_K	income share of capital input
t	time
U	rate of capacity utilization
u, v	error terms
w	wage rate
W	value of output or input
X	input variable
x, y	variables
Y	productivity index, total productivity
Y_K	capital productivity
Y_L	labour productivity
Y_M	materials productivity
$\alpha, \beta, \lambda, \gamma, \delta, \nu$	parameters
σ	elasticity of substitution
σ^2	variance

CONTENTS

1. INTRODUCTION

11.Background

Productivity is one of the most important means to improve human welfare. Together with increasing use of primary production factors, i.e. labour, capital and natural resources, it is a main source of economic growth. Productivity tends to improve social equality because it is a counterforce for inflation. Productivity is used as a criterion in investment decisions and collective wage bargaining. Information on international productivity differences serves as a basis for strategy formulation at branch and firm levels. These examples illustrate the key role of productivity in economic development and possible uses of productivity information.

Productivity is the relationship between output of goods and services and the inputs of resources, human and non-human, used in the production process (Kendrick 1977, 14). Measurement is based on volumes, not current money flows as in the case of profitability. Both outputs and inputs consist of components, i.e. individual goods or services and production factors. One of the key problems in productivity measurement is how to aggregate these components in a meaningful way.

Productivity is frequently examined as a partial measure, i.e. output volume against the use of one production factor at a time. The interpretation of partial productivity indicators is essentially limited by the *ceteris paribus* assumption vis-à-vis the use of other production factors. Therefore, the concept of total productivity has been introduced which refers to the relationship between output and all inputs. The aggregation problem is now extended to cover not only the different components of inputs but also the amalgamation of non-uniform production factors.

Productivity can be measured by means of productivity ratios and production functions. When ratios are calculated against two or more production factors simultaneously, an explicit or implicit production function is needed. Because of their holistic approach and causality, production functions have been used for obtaining information on productivity (cf. e.g. Walters 1963; Kennedy and Thirlwall 1972). On the other hand, a comprehensive review of partial productivity ratios produces results which cannot be derived from production functions (e.g. Gold 1955; Fricke 1961; Eilon e.a. 1976). The development of index theory has improved the analytical possibilities of total productivity ratios, which have been increasingly used in the 1970's, particularly in the United States (e.g. Christensen et al. 1973, Gollop and Jorgenson 1977; Diewert 1980).

Earlier studies on production functions in forest industries have often been limited to two branch aggregates (mechanical wood industry and pulp and paper industry) (e.g. Hildebrand and Liu 1965; Berndtson 1967; Åberg 1969; Griliches and Ringstad 1971): There is a wealth of studies about productivity ratios in the individual branches of the forest industries particularly in the United States but also elsewhere (cf. Simula 1979, 6).

Wohlin's (1970) study on the structural change and expansion possibilities of the Swedish forest industries deserves to be mentioned here because he successfully applied Salter's (1960) theory on productivity and technical change. Thereafter the same approach has been almost a routine in many branch studies in the forest industries (e.g. Technological . . . 1974; Sågverksindustri . . . 1977). Wohlin's study was followed in Sweden by Alvehed's (1971) attempt to measure total productivity and its dependence on capital intensity, plant size and other factors in pulp and paper production. In Finland, time-series analyses of production relationships in forest industries have been carried out by Cunningham (1974) and Simula (1979).

Solow's method (1957) on measuring technical change or total productivity has been tried for the pulp and paper industry in Canada (Manning and Thornburn 1971) and for the mechanical wood industries in the United States (Robinson 1975). The conclusions of these studies were limited by the branch aggregation in the data and the properties of the production functions applied. Stier (1980) used the dual cost function and Greber and White (1982) the method suggested by Sato (1970) to estimate the nature of production technology in the United States.

Førsund and Hjalmarsson (1979) had access to plant related cross-section data on the Swedish particle board industry which enabled estimation of the frontier production function. Their studies were further extended to the pulp industry (Førsund et al. 1980). In comparison to earlier research, these studies were an interesting improvement to the analysis of technical progress and structural change in the industry.

Pressmar (1971, 243–261) analyzed the production function of paper-making from the technical viewpoint, trying to establish the relationships between substance weight, product quality, machine speed, wire width, and the use of steam and water. This detailed approach, endeavouring toward engineering production function, separated gross and net relationships and suggested the consumption of production inputs be measured per output unit and time unit.

Earlier studies on productivity in the forest industries offer interesting results referring to the central characteristics of production, i.e. input elasticities, elasticity of substitution, rate of returns, the form of production function, etc., and the contribution to productivity by various underlying factors. Because of branch aggregation the meaningful interpretation of estimation results has, however, often been difficult. On the other hand, the available data and the adoption of the Cobb-Douglas production function as the analytical framework have frequently limited possibilities for detailed conclusions. In fact, the quality and extent of available data have perhaps been one of the main reasons why the limits of traditional production function analysis have been difficult to overcome.

12. Study Problem

At least in the short run the Finnish forest industries operate in a situation where they have to adapt to the market and price development of their products, while their possibilities to influence factor prices are limited. Institutional development in Finnish society has apparently reduced the parameters of decision-making at firm level and, therefore, productivity increase has been seen as one of the key measures to improve the industry's international competitiveness. Productivity measurement is independent of changes in unit prices and costs, exchange rates, and taxation or subsidies, although reactions to these changes are also reflected in productivity.

The international competitiveness of the Finnish forest industries, which operate primarily for export markets, weakened substantially during the first half of the 1970's (Suomen . . . 1979; Seppälä et al. 1980). This was partially explained by unfavourable cost trends. International comparisons with the other major producing countries revealed that the level of productivity was low in Finland, although the technical capability of main machinery and equipment would have assumed higher productivity than among the main competitors (Suomen . . . 1979, 74–77). This result, even though related to labour productivity only in the pulp and paper industry, has emphasized the need for more information on factors underlying productivity.

High unemployment levels in Finland, particularly since the mid-1970's, have placed more and more emphasis on the creation or preservation of employment. On the other hand, the open sectors of the economy, such as the forest industries, have to ensure their international competitiveness if they wish to continue to expand and offer new employment opportunities. New investment incorporating the latest technology has almost invariably lead to increased capital intensity and reduced unit labour input. Under these pressures adjustment of substitutable production factors, within the existing technological and economic limitations, can be an important tool for policy decision. This study tries to obtain information on the role of substitutable factor ratios as underlying factors for productivity. The primary inputs, labour and capital, have a special role here, because the substitution of one for another has traditionally been assumed easier than substitution between other inputs.

The evaluation of the use of production inputs by means of factor productivities consists of partial analysis, which, by definition, has a limited scope and may lead to non-optimum decision-making. The performance of the Finnish forest industries has traditionally been measured by these partial measures, notably labour productivity, or more frequently by profitability ratios. Because the latter ratios are influenced by changes in prices and costs, they provide little information on the rationale of using the real resources available for the industry.

The main purpose of the study is to obtain information on factors underlying productivity differences in the Finnish forest industries in 1974. Productivity is measured here with regard to labour, capital, materials, and total factor input. Energy productivity is not included in the study mainly for two reasons. There are serious measurement problems related to this input in the source data. Furthermore, since 1974 a lot of changes have taken place in the industry in energy productivity and therefore measurement results would have been of limited value.

In this study an effort is made to construct a total productivity indicator, which would relate the output volume to the use of a specified set of factors of production. The validity of the total productivity indicator also needs to be evaluated. A total productivity index always implies an underlying production function. Its properties need to be known before the function can be specified. The study aims at obtaining information on these properties, in particular the rate of returns, elasticity of substitution, and factor elasticities. The study also attempts to assess to what extent neoclassical average production functions can yield information on productivity variation. On the other hand, the results of productivity analysis may be difficult to interprete, if the properties of the underlying production function are not known.

The data of the study are derived from the file information of the Industrial Statistics of the Central Statistical Office in Finland. The study aims at judging to what extent these data can be used for productivity analysis, as they provide the only readily accessible information on the outputs and inputs of the Finnish forest industries at plant level.

Finally, the objectives of the study include a comparative evaluation of the information produced by time-series and cross-sectional data on the properties of production function and factors underlying productivity variation.

In summary the study aims at obtaining information on production relationships and productivity in the forest industries which can be used to improve the international competitiveness of the sector both at branch and plant level. This includes the search for appropriate comprehensive productivity indicators and the analysis of factors underlying productivity variation. The study does not include a review of the main characteristics of the industry since they have been sufficiently described elsewhere (e.g. Suomen . . . 1979; Seppälä et al. 1980).

13. Method of Study

The study reviews first the properties of alternative production functions which in this study serve two purposes. Firstly, they provide information on the characteristics of production relationships in the forest industries. This information is needed for establishing total productivity measures and identifying factors underlying productivity. Secondly, the estimation results of production functions contain direct information on certain aspects of productivity. A number of alternative functions are tested and efforts are made to improve their properties. The role of estimation bias is also evaluated. In order to avoid overexploitation of this information, there is also a need to discuss what is the possible interpretation of the estimated average production functions.

The establishment of total productivity indices aims to rely on theoretically acceptable, flexible and accurate measurement principles. An interpretation of cross-section total productivity measures is tried, and an attempt is made to verify the results. Finally, the total productivity indices measured serve as independent variables in productivity models.

Conceptual models are constructed for explaining factors underlying productivity variation at plant level. These models are specified separately for labour, capital, materials, and total productivity. The extent and nature of model relationships are evaluated by means of regression analysis, because the main focus is to establish the role of individual variables in productivity variation.

The final part of the analysis compares the cross-section and time-series estimations which are derived from similar analytical frameworks and the same source of data. The purpose is to find out to what extent the two approaches produce comparable results, and what kind of conclusions can be made concerning the short and long run changes in productivity.

The choice of the method of study was influenced by the available data. Because no vintage information was available on the plants, only average production functions were estimated even though more interesting results could have been obtained through so called frontier functions (cf. Chapter 211). Their estimation would have required observations of a number of production units established at the same time (and hence based on the same technology) but experiencing a variety of relative factor prices (cf. Bosworth 1976, 69). Another approach could have been to select typical comparable units within branches and carry out a detailed investigation on productivity factors at the shopfloor level. Such analyses can be very useful but the data collection is extremely costly if statistical validity of results is desired.

This study is analytical by nature and therefore optimisation methods have not been used. The selected approach was deemed justified as very little information has been available on productivity variation in the forest industries at plant level, and as the nature and coverage of the data used imposed a number of limitations. The chosen method of study has apparently several limitations, particularly with regard to the identification and operationalisation of productivity factors. It is therefore possible that many fundamental aspects may have been omitted in the analysis. Examples of such factors might include the quality of work environment, job satisfaction and motivation, organisation patterns, management skills, etc. These factors remain here outside the statistical causality and are reflected as "random" variation in estimation results.

2. PRODUCTION AND PRODUCTIVITY MODELS

21. Production Functions

Theory of production is based on production function, which describes the relationships between output and inputs. Production function explains how factors of production are thought to be transformed into outputs in the production process. In general form, production function can be written.

(2.1) $Q = f(X)$,

where Q represents outputs and X inputs. Their relationship implies that a technical maximisation problem has been solved or a given output is produced with a minimum quantity of inputs.

Production functions have several characteristics, and these influence their application in economic analysis. They can be specified *ex ante* or *ex post*, at micro or macro level, or in the short or long run; functions can refer to feasible region, they may be specified at a production frontier or they can be related to some average conditions. The nature of technology and the type of technical change adds two more dimensions to production theory. Production theory lacks a consensus of opinion. The analytical approach in individual studies must therefore be derived from the objectives of investigation within the limits of data availability. In this study the econometric estimates of production functions serve a number of purposes. They test alternative measurements of output and inputs, they assess the contribution to output by factors other than inputs, they provide information on the elasticity of scale and the nature of substitution between inputs, and they are used for constructing productivity indices.

Forest industries can largely be assumed to apply putty-clay technology. There are *ex ante* substitution possibilities between inputs, but once the plant has started its operation, these possibilities *ex post* are non-existent. This assumption can be refined further (e.g. Ollonqvist 1979) and it will be qualified in the following.

211. Frontier and Average Production Functions

In the factor space the traditional concept of production function is represented by an isoquant which specifies alternative technologies to produce a given output with the most efficient use of inputs, assuming that all the production functions are homogeneous and of first degree[1]. An isoquant refers to best-practice technology as it exists in each period either as observed or in blueprints, i.e. production possibilities. With technical change efficiency is improved and the isoquant moves towards the origin in the factor space.

If the isoquant (frontier production function) of an industry is known, it has been common since Farrell (1957) to define and measure the technical efficiency of an observed establishment (e.g. C in Figure 1) by comparing its input coefficients with the input coefficients on the isoquant or efficiency frontier for the same factor proportions (OB/OC in Figure 1). If the factor prices are equal for all establishments, a unit cost line can be constructed (EF in Fig. 1). Its tangential point on the isoquant represents both technical and price efficiency. The price efficiency of an observed establishment can be measured as OA/OB. Farrell's analysis rests on the assumptions of the homogeneity of the degree one, homotheticity of production function, and the cost-minimising behaviour of firms.

Alternative methods have been developed to estimate efficiency frontiers of frontier production functions from cross-section data (e.g. Aigner and Chu 1968; Timmer 1971; Carlsson 1972; Førsund and Hjalmarsson 1974). The methods require either vintage information or several time observations on each establishment, or calculations are extensive. In a study utilizing similar data to that in this study, Førsund and Hjalmarsson (1979, 84), however, concluded that their data did not contain sufficient information to

[1] $f(\lambda x, \lambda y) = \lambda^r f(x, y)$ when $r = 1$

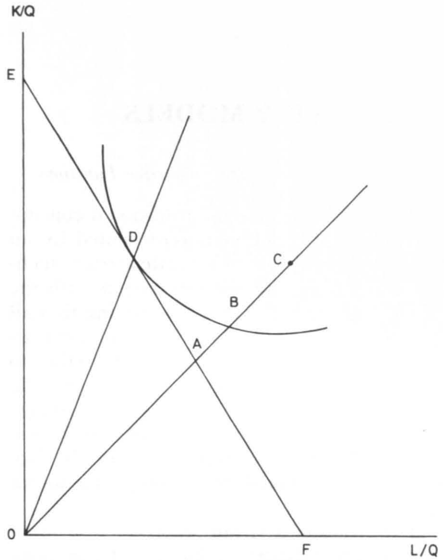

Fig. 1. Efficiency in Two-Factor Production Function (Source: Farrell 1957).

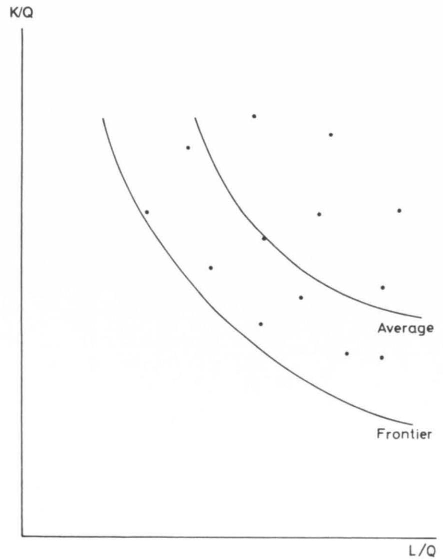

Fig. 2. Two-Factor Frontier and Average Production Function.

enable a proper *ex ante* function to be estimated with the specified form. Because the data of this study are apparently of poorer quality than theirs (Chapter 31.), the approach was rejected as serious interpretation difficulties were anticipated.

Another approach to study efficiency variation in a cross-section is to use some sort of average production function, which is located further away from the origin than the frontier production function in the input coefficient space (Fig. 2). Theoretically these two concepts are not directly linked because the parameters of an "average isoquant" are difficult to interprete meaningfully.

Average production function is a reflection of the past best-practice technologies and the existing vintage structure. It is some sort of an average of the technologies in use. Its parameters can be estimated but their interpretation cannot be directly derived from classical production theory. There is no general reason to assume that they should reflect the parameters of frontier production function. In the strict sense, an average production function does not describe technology at all, as any particular input coefficient combination may be associated with several technologies. On the other hand, average production function can be said to represent the prevailing technological structure of an industry in terms of average conditions. The parameters of such functions can be interpreted with reference to these average conditions. Frontier functions refer to best-practice technologies as they exist at a given point of time, while average production function represents the existing technologies of different vintages.

If the degree of homogeneity is estimated by an average function, it incorporates not only the rate of returns but also technical change embodied in different vintages. The results do not reflect the rate of returns of the best-practice technology as it exists at a given point of time. Analogously, the estimates of factor elasticities in average production functions describe changes in input coefficients relative to output changes in the average conditions of an industry over the existing technologies. The elasticity of substitution in average function can be interpreted as the

degree of easiness to substitute an input for another one in the prevailing mixture of technologies. The average elasticity of substitution does not illustrate the ease of substituting inputs within alternative best-practice technologies.

There is, however, a certain link between estimates derived from frontier production functions and average production functions but their relationships cannot be theoretically formulated and operationalised here. Average estimates may contain valuable analytical information on the structural properties of an existing industry but they cannot be interpreted as frontier estimates. If individual branches can *a priori* be considered relatively homogeneous, it is possible that some technical characteristics are still present in average production functions (cf. Bosworth 1976, 95).

In practice, the interpretation of frontier functions would be ambiguous in such branches as the forest industries. In principle, a cross-section observation represents a one-time best-practice technology. In the Finnish forest industries this is, however, seldom true. Modernisation and maintenance investments have changed the original technology and input coefficients. There are a large number of other factors which may also cause variation in input coefficients, such as the quality of inputs and outputs, unequal factor and product prices, management bias, etc. Already at the blueprint stage, many production units fail to reach frontier efficiency due to physical conditions. In Finland, the choice of technological variables in the forest industries is limited by the type and availability of wood raw material. Most new capacity expansions are made in the existing establishments where the available industrial facilities narrow the scope of decision alternatives. New mill sites are seldom born as the general tendency is to shut down inefficient production units. Both vertical and horisontal integration yields economic benefits in the forest industries. Choices as regards a particular process may be based on the overall costs and revenues of a whole integrate.

Non-optimum decisions on an individual process may therefore be made because of integration. For instance, the size of a particle board plant may decidedly be based on the available volume of mill residues produced by the adjacent sawmill and plywood mill.

212. CES Production Functions

The study is largely based on two types of neoclassical production function. The traditional Cobb-Douglas (CD) function is

(2.2) $Q = A L^{\alpha} K^{\beta}$,

where L is labour input, K capital input, and α and β are parameters. The function is linearly homogeneous; its elasticity of scale and its elasticities of output with respect to particular inputs are all constant as well as its elasticity of substitution, which is further assumed to equal one. The CD function is often transformed into

(2.3) $Q/L = A(K/L)^{\beta} L^{h}$,

where $h = \alpha + \beta - 1$.

The constant elasticity of substitution (CES) function (Arrow et al. 1961, 143) is obtained from

(2.4) $Q = \gamma \left[\delta K^{-\alpha} + (1-\delta) L^{-\alpha}\right]^{-v/\alpha}$,

where γ is a technical efficiency parameter and δ is a distribution parameter representing factor intensities. v is the returns-to-scale parameter representing the degree of homogeneity. The elasticity of substitution is assumed constant and it is derived as $\sigma = 1/(1+\alpha)$. The CD function is a special case of the CES functions.

In spite of its higher degree of generality compared to the CD function, the CES function includes a number of limitations. Change in the homogeneity parameter v incorporates both changes in the elasticity to scale and neutral technical change. The CES function is difficult to generalise for more than two factors, as partial elasticities of substitution have to be assumed equal (McFadden 1963; Uzawa 1962). Furthermore, the distribution parameter is dependent on the units of measurement.

Direct estimation of the CES function is not possible by simple linear regression techniques because there are second-order parameters in the function. Under the assumptions of cost-minimising behaviour and constant returns to scale the CES function has commonly been estimated as the side relation (Arrow et al. 1961, 138)

$$\ln (Q/L) = a + \sigma \ln w, \tag{2.5}$$

where a is a constant and w real wage. In the following this is referred to as the ACMS relation. The elasticity of substitution σ is now a first-order parameter, and its estimation can be made with some precision compared to nonlinear estimation of function (2.4) or two-stage iterative calculation procedures.

If the main purpose is to test the departure of σ from one, Taylor's theorem can be used to expand the CES function. If the third and higher order terms are omitted the following approximation can be used (Kmenta 1967):

$$\ln (Q/L) = a + b_1 \ln L + b_2 \ln (K/L) + b_3 \left[\ln (K/L)\right]^2, \tag{2.6}$$

where $b_1 = \nu - 1$, $b_2 = (1 - \delta)\,\nu$, and $b_3 = \frac{1}{2}\,\nu\,(1 - \delta)\,\delta\,\alpha$. If b_3 is not significantly different from zero, the CD form can be accepted. On the other hand, $b_3 \neq 0$ can be a result of a more general production function as alternative hypotheses are not limited to the CES forms. b_3 is a function of the elasticity of the substitution and the distribution parameters. Its value is likely to remain small and therefore, large samples with sufficient variation of the capital-labour ratio are needed.

The approximation is not a CES form and, therefore, the resulting parameter estimates are not independent of the units of measurement of L and K. Griliches and Ringstad (1971, 10) evaluated the elasticities associated with the approximate form at the geometric mean levels of the inputs and, in particular, at a level where the geometric means of the sample are equal. The elasticities derived from this kind of approximate formulations are to be interpreted as having been evaluated at the mean level of the sample.

If $b_3 \neq 0$ and is statistically significant, alternative techniques such as non-linear estimation can be used. Another possibility to obtain evidence on non-constant returns to scale is to add a size variable (e.g. output volume Q) to the ACMS relation (2.5) as Nadiri (1970, 1157) and Griliches and Ringstad (1971, 12) have suggested:

$$\ln (Q/L) = a + b \ln w + c \ln Q, \tag{2.7}$$

where Q can be replaced by L or K/L which would be reflected in the interpretation of parameter c. If $c \neq 0$, it supports the assumption that the elasticity of substitution is not constant over size classes, if expressed in terms of Q or L, or over the dispersion in the K/L ratio. These kinds of functions are called variable elasticity of substitution (VES) production functions. $c \neq 0$ does not, however, prove that elasticity varies, as it may be a result of other properties of the production function, e.g. that the homotheticity assumption implicit in the CES form is wrong.

In the VES specifications referred to above, the same variable Q occurs on both the right and left side of the function, and therefore the condition of non-correlation between the error term and explanatory variables is not satisfied. The endogeneity problem in function (2.7) can be reduced by estimating the function based on grouping into e.g. employment-size categories (Griliches and Ringstad 1971, 12) or by using such exogenous variables as capacity level as additional variables instead of Q, L or K/L.

In the Kmenta approximation the square term can be interpreted as a "constrained" version of a general plynominal form in the logarithms of the variables and thus its "unconstrained" version may be used to test the homotheticity assumption. The translog production function serves this purpose (Christensen et al. 1973).

$$\ln Q = a + b_1 \ln L + b_2 \ln K + b_3 \ln L \ln K + b_4 (\ln L)^2 + b_5 (\ln K)^2 \tag{2.8}$$

If $b_3 = b_4 = b_5 = 0$, the function collapses into the CD form. In general, the function is quite flexible in representing arbitrary producion technologies in terms of substitution possibilities (cf. Intriligator 1978, 280). The function has been used extensively although its theoretical properties and interpretation can be considered ambiguous.

There are a number of other neoclassical production functions in the literature, which relax assumptions on elasticity of scale or substitution. They are not reviewed here, because their possible additional contribution to the study problem at hand is deemed limited compared to the information derived from the CES class functions.

A priori assumptions on the properties of production function in the Finnish forest industries are difficult to make, not only because of the ambiguous interpretation of the neoclassical aggregate production function, but also due to the strict assumptions made on the homogeneity of factors of production and on the perfect competition on the product and factor markets. Earlier time-series studies (Simula 1979) are inconclusive, and therefore alternative hypothesis are tested in this study.

22. Total Factor Productivity Index

A productivity index can be a partial or total measure. Partial productivities (Y_i) relate the volume of output to the use of a single production input *ceteris paribus*, while total productivity (Y) is measured over all the used factors. The index of total factor productivity is typically computed as

$$\frac{dY}{Y} = \frac{dQ}{Q} - \frac{dX}{X}, \tag{2.9}$$

where X refers to total factor input. Sufficient conditions for the measurement of total factor productivity include the existence of consistent indices of both aggregate output and total input, which means that the underlying production function has a weakly homothetic separable form (Berndt 1980).

If the analysis is extended to incorporate price and quality data at discrete points of time, specific forms of production function are necessary. Christensen et al. (1976) and Gollop and Jorgenson (1977) used transcendental logarithmic functions or translog production functions for this purpose. Productivity change derived from the translog production is in the simplest two-factor case (cf. e.g. Gollop and Jorgenson 1977, 13)

$$\ln\left(\frac{Y_{t+1}}{Y_t}\right) = \ln\left(\frac{Q_{t+1}}{Q_t}\right) - \left[a \ln\left(\frac{L_{t+1}}{L_t}\right) + b \ln\left(\frac{K_{t+1}}{K_t}\right)\right], \tag{2.10}$$

where a and b are weights corresponding to average value shares in periods t and t+1:

$$a = \frac{1}{2}\left[\left(\frac{w_t L_t}{p_t Q_t}\right) + \left(\frac{w_{t+1} L_{t+1}}{p_{t+1} Q_{t+1}}\right)\right] \tag{2.11}$$

$$b = \frac{1}{2}\left[\left(\frac{g_t K_t}{p_t Q_t}\right) + \left(\frac{g_{t+1} K_{t+1}}{p_{t+1} Q_{t+1}}\right)\right]$$

w and g are unit input prices of labour and capital, respectively. The underlying translog production function assumes constant returns to scale and producer equilibrium as necessary conditions, which implies that the value of output is equal to the values of inputs.

If the true functional form for the total factor input index is not known, a superlative index should be used, one that is exact for a flexible functional form (Diewert 1980, 509). An index number is superlative if it is exact for a function which can provide a second-order approximation to an arbitrary linear homogeneous function. The Edgeworth weighting scheme in (2.11) is not free of measurement error.

In this study the value shares used as weights have been measured as logarithmic means or using the Vartia I index (Vartia 1976, 124–128). The index satisfies accurately both the factor reversal test and the time reversal test but usually the sum of the weights does not equal unity. This is not a disadvantage as at the same time the Vartia I index is consistent in aggregation. It belongs to the family of superlative indices (Diewert 1976). The weights of formula (2.10) can now be written

$$a = \frac{L(W^L_{t+1}, W^L_t)}{L(W_{t+1}, W_t)} \tag{2.12}$$

$$b = \frac{L(W^K_{t+1}, W^K_t)}{L(W_{t+1}, W_t)},$$

where $W^L = wL$, $W^K = gK$ and $W = pQ$ or the values shares of labour and capital, and the value of output, respectively. Logarithmic means are defined as follows, e.g.

$$L\left(W_{t+1}, W_t\right) = \frac{W_{t+1} - W_t}{\ln\left(\frac{W_{t+1}}{W_t}\right)} \tag{2.13}$$

In three-factor measurement, productivity change is

$$(2.14)\quad \ln\left(\frac{Y_{t+1}}{Y_t}\right) = \ln\left(\frac{Q_{t+1}}{Q_t}\right) - \left[a \ln\left(\frac{L_{t+1}}{L_t}\right) + b \ln\left(\frac{K_{t+1}}{K_t}\right) + c \ln\left(\frac{M_{t+1}}{M_t}\right)\right]$$

The value of output is now measured in gross terms, while in the two-factor case it is based on value added. The weight of materials input is

$$(2.15)\quad c = \frac{L\,(W^M_{t+1}\,,\,W^M_t)}{L\,(W_{t+1}\,,\,W_t)},$$

where W^M is the value share of materials input.

In the above formulae measurement is based on changes, which partly reduces the problem of aggregating heterogeneous factors of production. If quality change is included in the measurement of output and input variables, the measurement of changes is further justified because of the difficulties involved in the measurement of quality levels of variables.

If productivity change is interpreted as technical change, it is nearly Hicks-neutral because of the homogeneity of the underlying production function. Measurement based on variables with quality change included can be compared to measurement with no quality change in variables in order to assess the importance of embodied and disembodied technical change in productivity development.

In the foregoing analysis subscripts t and t+1 have referred to different time periods but they can analogously refer to successive observations in a cross-section. The interpretation of total productivity is, however, different and depends on how the cross-section observations have been arranged.

The weights used in productivity measurement can be fixed, variable, or they can be changed at certain intervals. In time-series analysis preference should be given to periodically changing weights, if there is not sufficient evidence to support assumption of linear homogeneity of production function and constant elasticity of substitution (Simula 1979, 51). In cross-section measurement the choice of weighting scheme depends on how the observations have been arranged and what is the purpose of measurement. If some sort of average weights are used over the whole cross-section, an assumption on an average fixed technology is implied, and this is difficult to justify. If the observations are in vintage order, changing weights at certain intervals would usually be preferable according to the same argumentation as in time-series analysis. Productivity measurement would then reflect changes in market structure, elasticity of scale, elasticity of substitution, quality of variables, and the nature of technical change. Following Diewert's (1980) suggestion the chain principle of weighting is applied in this study rather than fixed base or some sort of grouped average.

Total productivity can be measured in terms of capacity level of output and inputs or in terms of their actual volumes. Although the measurement at capacity levels has some advantages, there is a general consensus that the actual volumes should be used as the basis (e.g. Christensen and Jorgenson 1973; Kendrick 1973, 26; Denison 1974, 56; Gollop and Jorgenson 1977, 141).

23. Productivity Model

The neoclassical production functions discussed in chapter 21. mainly focus on the explanation of changes in output in terms of factor inputs. Output volume or labour productivity only appear as dependent variables. Other approaches are therefore needed to expand the scope of productivity analysis. In this chapter a conceptual model is presented for analysing factors influencing individual partial productivities and total factor productivity. The formulation of the model is, however, constrained by the available data.

It is assumed that firms in the Finnish forest industries endeavour to minimise their production costs. Output and input volumes are chosen based on their present and expected unit price development. The unit price of output is primarily determined outside an individual firm. The bulk of production in the forest industries is exported and in no major product can Finnish exporters be considered price makers. The sales price is largely determined by other suppliers. Rather than reduce prices during recessions the industry curtails its production level.

Wages and salaries are largely determined by collective bargaining between the trade unions and the employers' association of the industry. Local adjustments are frequently made and, in certain cases, the wage drift has been larger than the agreed increase in wage rate. A substantial part of the decision-making power on wages and salaries is, however, in general, outside individual firms.

Apart from sawmilling the Finnish forest industries are characterized by a relatively small number of major companies, which have interests in several branches of the industry. They co-operate through various joint organizations to establish guidelines for stumpage values with the central association of forest farmers. During periods of keen demand stumpages also tend to slide upwards from the agreed levels. The unit prices of purchased energy and chemicals for the Finnish forest industries are partly determined by world market prices. Also the price of capital input is exogenous. Forest industry firms have only limited possibilities to influence their financing costs. It can be concluded that the cost-minimising behaviour of firms is a matter of choosing volumes of individual outputs and inputs within the present and anticipated prices, which are largely beyond the control of a single firm.

Cost minimising or profit maximising should yield the same outcome as maximising total productivity assuming a linear and homogeneous production function and using the duality theorem:

Profit maximisation:

$$\max.\; pQ - (wL + gK)$$

Productivity maximisation:

$$\max.\; \frac{pQ}{(wL + gK)}$$

If the denominator is not taken as an approximation of production function (in cases where its properties cannot be tested) but simply as a way of aggregating inputs for measurement purposes, the homogeneity assumption is not necessary. The interpretation of unit prices is not, however, necessarily the same in the above formulae. In profit measurement price refers to the current price of each item, while in productivity measurement it is a weight and may be calculated as some sort of average over items or time.

Total productivity is a relatively abstract measure and in practice it has seldom been calculated at firm level. Total cost would therefore appear a more relevant measure but if the two criteria are parallel, maximisation behaviour can be applied for both types of analyses. The maximisation of profitability should lead to maximum total factor productivity and both of them could be used as operational decision variables. Total productivity is a specific combination of individual factor productivities within the limits of the prevailing production function (or other input aggregation schedule used in the compilation of productivity measure). Substitution of inputs represents a problem if individual factor productivities are analysed within the above-mentioned framework. In a typical case, when labour is substituted for capital at a given output level, capital productivity reduces while labour productivity increases. If e.g. plant size changes at the same time, these impacts become less clear to analyse.

Substitutable inputs play a special role in productivity analysis. In this study their ratio is considered a possible decision variable which reflects the chosen technology but also transfers the impacts of several underlying factors on productivity. At the planning stage, it is often assumed that in an industry there are ample possibilities to substitute labour for capital. In the forest industries the practical possibilities for varying unit input coefficients are relatively limited, as the minimum economic size of a plant is in many cases relatively large. Substitution can be assumed difficult because there are relatively few alternative processes available for each major product. Furthermore, the individual specifications of machinery and equipment suppliers are relatively few and standardised. *Ex ante* elasticity can, therefore, be assumed different from the putty-clay model.

In general, productivity can be assumed to depend on substitutable input ratio, input and output quality, input prices, plant size and product demand. The characteristics of the production process have an impact on the substitutable input ratio which partly determines the quality characteristics of inputs and outputs. Quality is reflected in unit prices which are exogenous as discussed above. The price relationship effects both the substitutable input ratio and productivity. The choice of production process and possible capacity range are partly interrelated. Choice of plant size is based on market possibilities, wood raw material availability, and profitability where the impact of integration may be significant. Decisions on capacity level determine the possible range of substitutable input ratio and productivity.

Product demand determines exogenously to what extent the existing production facilities can be used, which is reflected in the rate of capacity utilization. In forest industries the short-term variation in this rate can be large. Inefficient plant design, raw material availability and other reasons may explain why capacity utilization may remain lower than the markets would allow.

The model described above is illustrated by Figure 3. The model does not include vintage because it was not possible to find an operational way for its measurement in this study. This is contrary to Salter's (1960) theory which advocates for the existence of embodied technical change. As evidence is inconclusive or suggestive at most (e.g. Gregory and James 1973), the exclusion of vintage effects may not be critical to the results of this study. In forest industries plant size cannot be used as a proxy for vintage, as in some other branches, because it is presumed that the choice of capacity level is often more closely related to local conditions than vintage.

Either total factor productivity or alternative factor productivities can be interpreted as the productivity measure in the model. Because of substitution relationships it is not, however, assumed that firms attempt to maximise all productivity measures equally. If maximum total productivity is aimed at, it is possible that the use of some inputs is inefficient for internal reasons. These kinds of limitations are assumed to be reflected in substitutable input ratio. In the following, the general model is qualified for individual productivity measures.

It can be assumed that decisions on the levels of output and labour input are partly simultaneous. They behave differently during business cycles. During recovery the use of labour is first increased by raising over-time work and then by recruiting. The recruited labour is first of lower than average quality in the industry because it has not yet been trained for the job. During recession the reduction of labour force takes place slowly, mainly through refraining from new recruitement. For these reasons, cycles tend to be more pronounced in labour productivity than

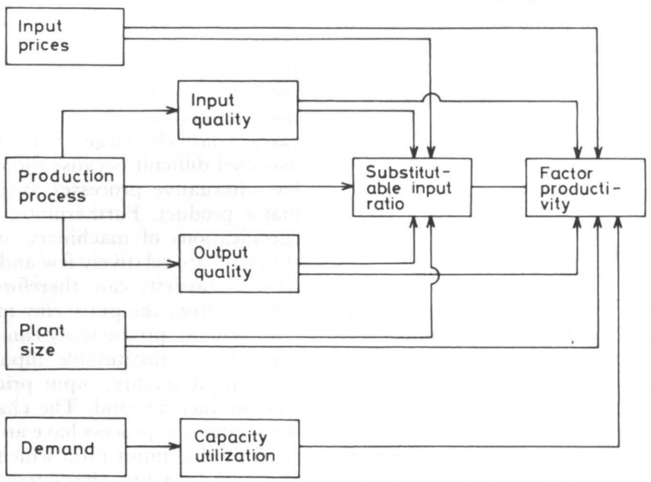

Fig. 3. General Model of Productivity in the Forest Industries.

in output. Labour is a less rigid factor of production than capital but it is also less flexible to adjust than e.g. materials input. In this study labour is considered endogenous, although there are reasons to assume it exogenous as well, particularly in pulp and paper production, where labour input has been less flexible to adjust than in the mechanical wood industries.

Labour productivity is assumed to depend on capital-labour ratio, which reflects the technological choices with regard to the characteristics of production process and plant size. These two factors also influence labour productivity directly. The quality of labour force and output are reflected in the K/L ratio and also directly in labour productivity. Price relationships of capital and labour have an impact on the K/L ratio at the investment stage but they also influence *ex post* labour productivity within the limits of possible adjustments in the existing plant.

Forest industries are not very labour intensive. The share of labour costs of the gross value of production is highest in sawmilling and plywood production. The rest of the industry (particle board, fibreboard, pulp, and paper) is typically capital intensive. There is hardly a reason to assume that firms would generally maximise labour productivity from the viewpoint of maximising profit or total productivity. However, various institutional factors such as legislation, the changing role of trade unions etc., suggest that the industry may have other than economic incentives to minimise their labour input per output unit. Once the plant has been established, labour input becomes a focus of efficiency improvement efforts. Possible improvements may or may not require additional capital investments. The variation of labour productivity in the existing industry reflects therefore both *ex ante* and *ex post* decisions. The maximisation of labour productivity is assumed to be a relevant concept, particularly *ex post.*

Capital productivity or output-capital ratio is primarily determined *ex ante.* It is influenced by the characteristics of production process and plant size. With regard to unit investment costs the economies of scale are well documented in the forest industries (e.g. Guide. . . . 1973, 129–132; Guidelines . . . . 1975). The hypotheses on maximising capital productivity can be justified because of the forest industry's general capital intensity. The technological choices are reflected also in the K/L ratio, which in this case is influenced by the quality of capital. The K/L ratio can also be postulated as a factor having impact on capital productivity. Other underlying factors include input price ratio and output quality. As in labour productivity, exogenous product demand determines to what extent the available capacity can be utilized.

The use of materials input can be assumed relatively fixed with output level in a single plant in the short run. In the long run and across plants substantial variation is possible. Materials productivity is assumed to be influenced by production technology as reflected in plant size and process characteristics. There are some, but presumably limited, possibilities to substitute materials for labour in the forest industries and therefore the L/M ratio can be included in the analysis of materials productivity. The role of the L/M ratio is presumably weaker than that of the K/L ratio in analysing labour productivity and capital productivity. More opportunities for substitution could be found between the individual components of the materials input such as wood and energy or wood and chemicals. The analysis of these relationships are beyond the scope of this study. Materials productivity is further influenced by its own quality and unit price, output quality, and production technology. The rate of capacity utilization may also be reflected in materials productivity.

The general model aimed at explaining the variation in productivity between plants in the forest industries can now be written

$$(2.16) \quad Y_i = f\left(\frac{X_i}{X_j}, X_i^q, q, \frac{p_i}{p_j}, P, C, U\right)$$

where Y_i is a productivity measure, X_i/X_j substitutable input ratio, X_i^q input quality, q output quality, p_i/p_j input price ratio, P process characteristics, C plant size, and U the rate of capacity utilization. Based on the theory of production (Chapter 21.) the functional form of productivity models can be assumed log-linear. The model is assumed general for individual partial and total productivity measures and for individual branches and their aggregates in the forest industries.

3. DATA, VARIABLES AND ESTIMATION METHODS

31. Data Sources and Preparation

The principal source of data in this study is the 1974 questionnaires of the annual Survey on Industrial Activity in Finland, carried out by the Central Statistical Office. The survey covers all the manufacturing establishments as defined by the Finnish Standard of Industrial Classification. The following branches are included in the study:

	ISIC code
– Sawmills	331111
– Mechanical Wood Industry	331111, 331191, 331192
– Pulp Mills	34111
– Paper Mills	34112
– Pulp and Paper Industry	34111, 34112
– Forest Industry	331111, 331191, 331192, 34111, 34112

Mechanical Wood Industry includes sawmills and planing mills as well as plywood and particle board plants. Because of the small number of observations wood-based panel industries are not analysed separately. Pulp Mills include the non-integrated and integrated establishments manufacturing mechanical, semi-chemical, sulfite and sulfate pulp. Paper Mills include both paper and board manufacturing. Pulp and Paper Industry covers the two previous groups, and Forest Industry pools the observations of Mechanical Wood Industry and Pulp and Paper Industry. The estimations were thus carried out at three levels of grouping to assess the impact of aggregation on results.

Since individual establishment data are confidential in the Survey of Industrial Activity in Finland, the establishments were arranged into groups containing a minimum of three observations. Each group was designed to include as homogeneous establishments as possible. Criteria used in this classification were process and main product, plant size, start-up year, degree and nature of integration, type of wood raw material, and geographical location. The aggregated data for each group were divided by the respective number of establishments to represent with a theoretical average establishment in each group.

The individual plants of an integrate are reported separately in the Survey of Industrial Activity. If an integrate has a joint repair and maintenance department serving several production lines, it is classified as metal industries in the Finnish statistics. These metal industry "establishments" were also identified and added to the data of the most important individual establishment of the integrate in terms of gross output.

The Survey of Industrial Activity does not gather information on capacity. The capacity data were obtained from the data bank of Jaakko Pöyry International Oy, Helsinki, Finland.

After checking and test runs several observations were rejected. The final sample consists of 29 observations in Sawmilling, 41 in Mechanical Wood Industry, 14 in Pulp Mills, 12 in Paper Mills, 26 in Pulp and Paper Industry, and 67 in Forest Industry.

The reliability of the data can duly be questioned because of the errors contained in the Survey of Industrial Activity and the manipulations described above. Other possibilities to obtain cross-section information on the Finnish forest industries at reasonable cost were not, however, available for this study.

The data refer to the year 1974. The pulp and paper industry was then operating in a situation with no market limitations. It can be assumed that in 1974 the industry was in a position to realise its productivity potential within the limitations of the available inputs. The peak of the business cycle in the mechanical wood industry was, however, already reached in 1973. The production in 1974 was at a somewhat lower level, and therefore the results of the two main branches are not strictly comparable. However, it can be assumed that by branches individual plants were facing similar market situations.

After necessary transformations (Chapter 32.), geometric averages were calculated for each variable. The observations were then indexed and natural logarithms were taken for model estimation. The original data are given in Appendix 1.

32. Variables

A detailed discussion on the theoretical and empirical difficulties in measuring output and input variables in the Finnish forest industries has been presented elsewhere (Simula 1979), and therefore only a brief explanation on the variable measurement is given in the following.

Earlier experience (Simula 1979, 137–142) has indicated that the estimation of production function and productivity models is particularly sensitive to the choice of output variable. Therefore, several alternatives were tested, of which the models with physical output of the main products produced (Q_F)[1], annual capacity of physical output (C), and net output (Q_N) are reported in the following. Net output is value added minus purchased industrial and other services and a number of smaller cost items. This indicator is particularly interesting for labour productivity measurement as the varying use of external services does not bias the results. Because of the ambiguities related to the establishment of transfer prices in integrated pulp and paper mills the net output-based measures possibly include a measurement error, particularly in Paper Mills. Furthermore, net output measure is influenced by the geographical location of the establishment mainly through transportation cost of raw materials and outputs.

The output quality was measured by the average output price of the main product (p), the share of value added in the gross value of output (q_1), and the share of the sales value of the main product(s) in the gross value of output (q_2). The quality variables tested describe somewhat different aspects. The price variable is perhaps most directly related to quality if comparisons are made within relatively homogeneous product groups. The observations are, however, biased by varying transportation costs since prices are ex-mill. q_2 can be considered an indicator of specialization, while q_1 attempts to illustrate the degree of conversion.

The rate of capacity utilisation (U) was measured by the ratio of physical output volume of the main product(s) to the respective physical production capacity. The potential role of U is important in the analysis. If it is linked with productivity, it can be assumed that the volume of capital and labour used is planned according to a certain standard (full) rate of capacity utilization. If there is no correlation, the industry's adjustment process has been successful or the industry has operated at this standard rate.

The labour input variables were number of employees (L) and number of employee hours (L_H). The quality, mix, and related aspects of labour input were measured in terms of the share of salaried personnel in the total number of employees (L_S), the percentage of technical staff in the number of workers (L_T), the share of the hours of production workers in the total hours of all workers (L_W), the average cost of employee hour or the sum of salaries, wages and fringe benefits divided by number of total hours (w), and the average hours per employee per annum (L_U). The first three variables describe only certain aspects of quality, while w refers to the total labour input. The share variables do not necessarily reflect only quality, as they are also influenced by e.g. the type of organization. The variable w serves the employer's viewpoint of quality, which assumes that the contribution to output of each input component is related to its cost. L_U may be interpreted as an indicator of the intensity of labour utilization but it is also influenced by such factors as shut-downs, strikes, etc. Based on correlation coefficients, L_S and L_T appear to describe essentially the same quality aspect in pulp and paper production, while in the mechanical wood industries this relationship is weaker. Labour input price generally correlates positively with L_S and L_T. L_W has smaller variance than L_S and L_T and it behaves independently from them. L_U does not correlate systematically with the other variables of labour quality.

The amount of capital (K) is measured as the total replacement value of buildings,

[1] Excluding by-products, saleable waste, residues, etc.

machinery, equipment, and related items. The replacement value refers to the full fire insurance value of capital goods owned by the establishment at the end of the year, adjusted by the owner's risk. Rented capital goods are excluded but their importance in the Finnish forest industries is limited. The quality of capital (K_q) is conventionally measured as the share of machinery and equipment in the value of K. Two material input variables were used, value of raw materials and supplies purchased (M) and volume of wood raw material used (M_V). The latter variable refers to the primary wood processing industries only and excludes all branch groups where paper manufacturing is represented.

Several dummy variables were constructed for individual branches to investigate possible differences caused by process characteristics, scale of production, degree of conversion and integration. The process dummy (D_{1i}) differentiates frame-saws from other sawing methods in sawmilling; mechanical and semichemical pulping, sulfite, and sulfate pulping in pulp production; wood-containing printing and writing paper, wood-free printing and writing paper, unbleached and bleached kraft pulp-based paper and board, and folding boxboard and speciality papers in paper and board production. The process dummy was also defined for aggregated branches; in Mechanical Wood Industry sawmilling and wood-based panels are differentiated, and in Pulp and Paper Industry pulp is differentiated from paper production. The use of the process dummy attemps to investigate the homogeneity assumption over alternative processes.

The scale dummy (D_{2i}) divides the observations in terms of annual production capacity, and it serves the testing of the hypothesis of constant returns to scale in the existing plants. The third group of dummy variables (D_{3i}) refers to further conversion and integration. The sawmills with important further conversion activities such as planing and prefabricated house or joinery production are differentiated from those primarily producing rough sawnwood. In pulp industry the dummy separates non-integrated market pulp mills from those integrated with paper production. In paper production a difference is made, whether the mill is integrated with mechanical or chemical pulp production. This group of dummy variables attempts to investigate, whether the homogeneity of production functions is subject to the degree of conversion or integration benefits within an individual branch.

A regional dummy variable would have been interesting to investigate since many of the value measures applied were biased by transportation costs. This was not possible, however, because the original pooled observations came from a minimum of three plants often in distinctly different locations.

The value-based measures are likely to be most affected by measurement errors, not only because they are influenced by transportation costs but also as a result of the way they are aggregated. The accuracy of data may also be correlated with plant size, particularly in sawmills where small units may have less detailed and accurate accounting systems than large mills.

33. Estimation

Production functions and productivity models could have been estimated using least-squares regression analysis, maximum likelihood estimation proper or Bayesian estimation. Under certain assumptions the two first methods are equal but because of its theoretical basis maximum likelihood estimation should be preferred. The unbiasedness, effectiveness and consistency of least-squares estimates are influenced by simultaneous relationships between variables and measurement errors in independent variables.

The use of the maximum likelihood method is particularly suitable for estimating overidentified models. Overidentification is typical of the models estimated in this study. When estimating the CES function based on maximum likelihood the point distribution of error terms, the non-linearities of production, and marginal productivity conditions are explicity taken into account (Bodkin and Klein 1967). Probability function is based on the production function and the variances and covariances of stochastic terms. Iterations are made using *a priori* initial values of parameters, until the sum of squares of error terms reaches minimum and the values of parameters approach certain values. This procedure

is sensitive to the choice of initil values. In spite of its theoretical appeal the method is not applied here because of lengthy calculations.

In Bayesian estimations *a priori* restrictions of the distribution of parameters and error terms are necessary. Average production function is estimated directly instead of best-practice technology, and the assumption of profit maximisation can be eliminated. In this study sufficient information was not available to make reasonable *a priori* assumption on parameters and errors terms. The Bayesian method is sensitive to the choice of initial values, and therefore the method was rejected here.

Single equation models were estimated using the ordinary least squares (OLS) method. In spite of their deficiencies compared to alternative methods the OLS calculations are flexible and simple, still offering versatile possibilities for econometric analysis. The OLS method is more robust against specification errors than many of the simultaneous equation methods. The predictions from equations estimated by OLS often compare favourably with those obtained from equations estimated by simultaneous equation methods (Maddala 1977, 231). Specification error due, in particular, to omitted variables is presumably a dominant problem in this study.

With two or more cross-sections for the same plants it may be possible to reduce the effects of simultaneity by means of covariance analysis (Mundlak 1961; Hoch 1962). The error term of a production function has to absorb differences in management and environmental factors between plants. It can, therefore, be assumed that there is a correlation between the error term and the inputs. The OLS estimators are consequently subject to a kind of simultaneous equation bias. However, Ringstad (1971, 79) concludes that the covariance method, based on two or more measurements of the same plants, is not very robust against measurement errors. The method is rejected here as only one measurement was possible.

Multicollinearity is not usually as serious a problem in cross section as in time series. Its presence influences, however, the values of parameter estimates, their standard deviation, and thereby their statistical significance. General conclusions on multicollinearity are difficult to make as e.g. in CD functions good estimation results have been reached in spite of high correlation between explanatory variables (.8 . . . .9) when the multiple correlation coefficient has been higher than .95 (Klein 1962, 101). In production functions it is common to eliminate multicollinearity by imposing restrictions on parameters. This would, however, limit estimation to a certain part of parameter space. Several suggestions have been presented for these kind of model modifications (e.g. Theil 1971, 154). There is, however, no guarantee that they would improve estimation results and therefore they were not used in the study.

The goodness of fit was evaluated using the adjusted multiple correlation coefficient ($\bar{R}^2$) as a guide (Goldberger 1966, 217). Compared to the nonadjusted multiple correlation coefficient (R^2), $\bar{R}^2$ is the lower the more variables there are in the model. ($\bar{R}^2$) prefers models which have smallest residual variance. With low R^2 and few degrees of freedom $\bar{R}^2$ can obtain negative values, which are not, however, reported. Other criteria of model evaluation include standard error of estimate, the significance of parameter estimates as measured by the t-test, and F-test to measure the overall significance of the regression equations.

The estimation of biases has been explained in Chapter 514.

4. MEASUREMENT OF PRODUCTIVITY

41. Indices and their Weighting Schemes

This chapter has three purposes, which are to measure total factor productivity in a cross-section; evaluate how the results differ in two-factor and three-factor measurement; and evaluate how the choice between value-based and physical volume-based output variables influences the measurement.

Total productivities have been calculated using formulae (2.10), (2.12), (2.14), and (2.15) as follows:

Y_1 – two-factor productivity measure, where physical production volume (Q_F) is used as output indicator, number of employee hours (L_H) as labour input, and the capital stock adjusted by the rate of capacity utilization (K_U) as capital input;

Y_2 – two-factor productivity measure, where net output (Q_N) is used as output indicator and the input variables are as in Y_1;

Y_3 – three-factor productivity measure where Q_F is used as output indicator, L_H as labour input, K_U as capital input, and as materials input the volume of the wood raw material used (M_V) in primary wood-processing industries and the value of materials input (M) in Paper Mills, Pulp and Paper Industry, and Forest Industry; and

Y_4 – three-factor productivity measure where gross value of output (Q_G) is used as output measure and other variables as in Y_3.

The observations were ranked by plant size which was measured in terms of physical production capacity. This was considered the best available alternative there being no vintage information on the machinery. Capacity can be regarded as a better indicator of plant size than such alternatives as number of employees or volume of output, which tend to vary in the short run. The measurement of output and input variables includes no quality changes. If quality is taken into account, it can be assumed to eliminate a part of the variation in total productivity.

The weights of the index formulae (2.10) and (2.12) were calculated using formulae (2.12) and (2.15), where t and t+1 refer to successive observations in the order of plant size. The role of weights in the total productivity indices is to aggregate the total factor input. The weights reflect the contribution to output of each input and therefore the chosen production technology. The underlying assumption is, in this case, that plant size is the most important characteristic of technology when analysing productivity variation between plants. The weights used partly reflect changes in the structure of the markets (deviation from perfect competition) and they are influenced by technical change. The weights derived from the annual value shares of inputs tend to vary extensively over time. In cross section it can be assumed that the firms are facing a largely identical situation in their factor and product markets. If the cross section represents a boom year as here (in the pulp and paper industry), it is possible that the residual-based factor share of capital input exceeds or corresponds approximately to its contribution to output.

Another possibility would have been to use fixed average weights for all observations within a branch. This was deemed unjustifiable because of the necessary assumtion of constant returns to scale, which is unlikely to be true in a cross section representing a very long history of investments, up to more than 80 years in some cases in the pulp and paper industry. Had vintage information been available, it would have been possible to group observations within a branch and to use fixed weights for these groups.

In total productivity measurement the flow of capital services would be preferred to that of capital stock. In this study, it was not, however, possible to calculate the service flow of capital in a reasonable way with the available data which lacked information on e.g. working capital. Based on the experiments made with other kind of data on the Finnish forest industries it can be assumed that the two methods would have produced largely

similar results for the purposes of this study (Suomen . . . 1979).

Index values of output and input variables were used to calculate total productivity changes over successive observations. The changes were then chained and indexed using the smallest plant as the base value. Only three branches are reviewed, i.e. Sawmills, Pulp Mills and Paper Mills, which represent the least aggregated industries studied. The results are presented in Chapter 42. and Chapter 43. discusses the relationships between total and partial productivity measures.

42. Total Productivity by Branches

421. Sawmills

Alternative productivity indices produce a relatively consistent picture of the variation in total factor productivity in the sawmilling industry (Fig. 4). The highest two-factor physical volume-based productivities were reached by mills representing units where vertical integration is extensive (observation 11), and by medium to large-scale mills which are horizontally integrated with a pulp mill. The largest non-integrated mills did not have as high a productivity as could have been expected. In general, total productivity appears to have a relatively narrow range, i.e. from 0.4 to 1.9 times its initial level.

The net output two-factor measure (Y_2) moves generally to the same direction as Y_1. Its values are, however, lower with a few exceptions. The three-factor ratio based on physical output (Y_3) yields values for the most part somewhat lower than Y_1 but higher than Y_2. It is clearly above the respective two-factor ratio in the largest mills, which could indicate that the size is more positively related to materials productivity than to labour or capital unit consumption.

A slightly upward trend can be identified in Y_4 up to the size class of 50 000 to 100 000 m^3/a, but in the largest mills its value tends to reduce. The standard deviations of the physical volume-based measures are larger than those of the value-based indicators (Table 1). The incorporation of the materials input in the index reduces its variance and this can be interpreted such that a part of two-factor productivity variance may originate from the use of materials input.

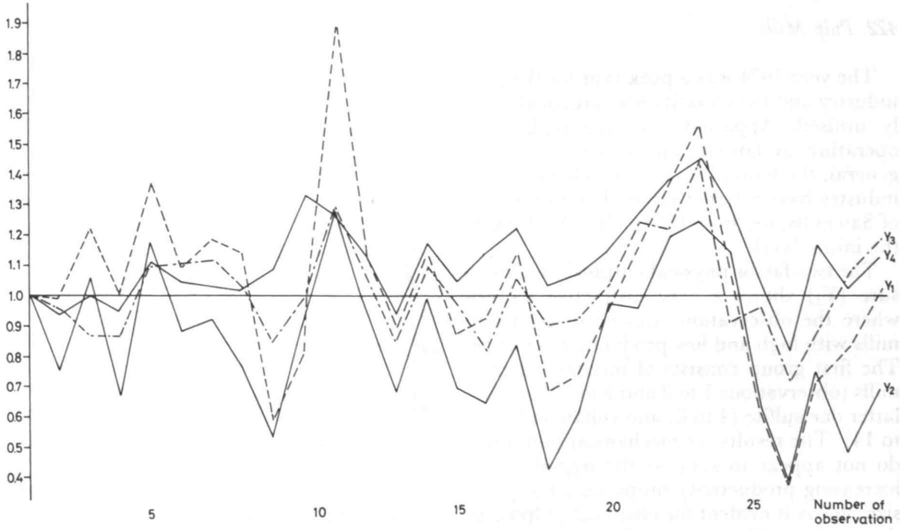

Fig. 4. Total Factor Productivity Indicators in the Sawmilling Industry 1974.

Table 1. Standard Deviation of Total Productivity Indices

Productivity Index	Sawmills	Pulp Mills	Paper Mills
Y_1	.318	.591	.488
Y_2	.307	.271	.422
Y_3	.150	.235	.412
Y_4	.128	.181	.196
Number of observations	29	14	12

The measurement results do not appear to support the relevance of the effect of plant size to total productivity in the Finnish sawmilling industry. In particular, the low values reached by the largest mills may be an indication of diseconomies of scale. It is possible that when the capacity is extended well above 200 000 m^3/a the use of production inputs may as a whole, be less efficient than in the best mills of size class 50 000 to 100 000 m^3/a. Integration may, however, bias these conclusions, if the use of inputs is optimized at the level of the whole complex. The result may also be taken as an indication of the possible existence of progressive technological steps in sawmilling.

422. Pulp Mills

The year 1974 was a peak year for the pulp industry and the capacity was practically fully utilised. Apparently all the mills were operating in largely similar conditions. In general, the total productivity indices for this industry have a larger range than in the case of Sawmills, i.e. from 0.5 to almost 3.0 times the initial level.

The two-factor physical output-based measure (Y_1) shows a very distinctive pattern where the observations can be divided into mills with high and low productivity (Fig. 5). The first group consists of mechanical pulp mills (observations 1 to 3 and 9 to 10) and the latter one sulfite (4 to 8) and sulfate mills (11 to 14). The results for mechanical pulp mills do not appear to support the hypothesis of increasing productivity proportional to plant size, nor is it evident for chemical pulping in the existing mills when two-factor productivity is measured by physical output. It is posible that in this industry other factors, e.g. the age of main machinery and equipment, have more influence than plant size on total productivity. Pulp industry is largely integrated with paper production. Transfer prices have been used in the valuation of output in integrates. These prices may divert from market prices, particularly in the production of mechanical pulp and unbleached chemical pulp, thereby influencing the results.

When productivity measurement is based on three factors and physical output (Y_3) its variation is substantially reduced (Table 1) but the two groups of plants remain distinctive. The incorporation of the wood raw

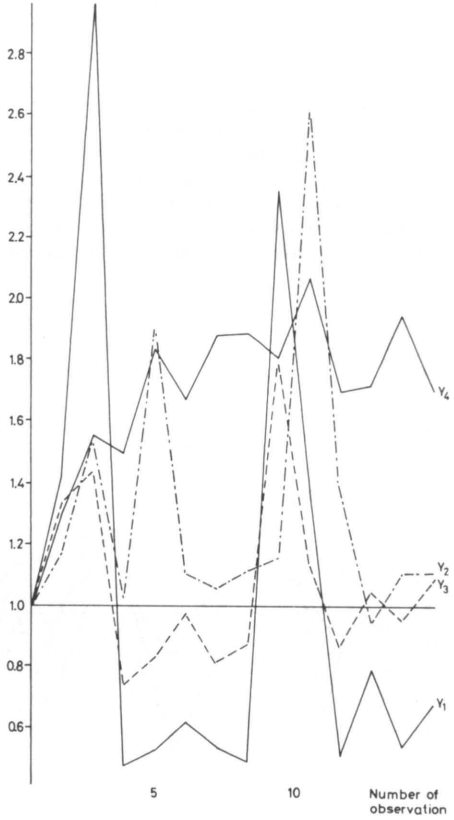

Fig. 5. Total Factor Productivity Indicators in the Pulp Industry 1974.

material input introduces an upward trend for productivity in each group. Unit wood consumption in mechanical pulping is only about half of that in chemical pulp production, which influences productivity levels. The slightly upward trend by groups can be assumed to be a result of technical change, if plant size correlates with vintage. This assumption can, however, be only partly true in the Finnish pulp industry.

The three-factor output value-productivity (Y_4) is distinctly different from the other indicators. Process no longer has such an influence on productivity, as above. The upward trend turns slightly downwards in the largest mills. This is surprising as the result does not

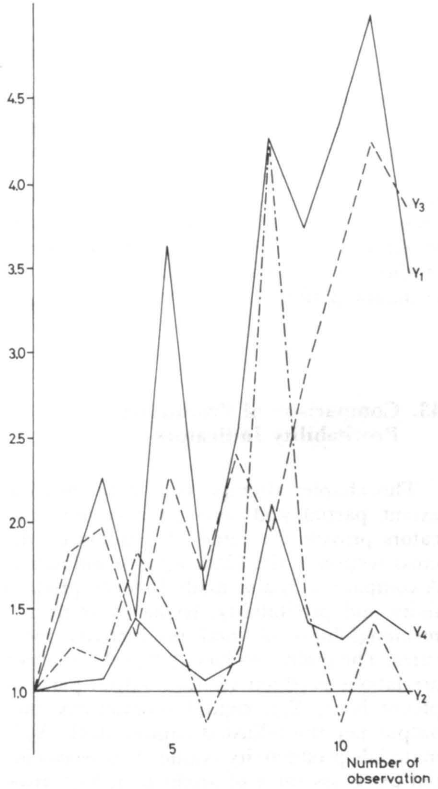

Fig. 6. Total Factor Productivity Indicators in the Paper Industry 1974.

reflect the impact of differences in unit wood consumption, the most important individual input factor. In the indicator Y_4 process looses its importance when explaining the differences in productivity. Increasing economies of scale can be assumed based on the results but there is a possibility for diseconomies of scale beyond a certain size in the existing industry. This conclusion is not necessarily valid for modern plants as some of the largest mills in the data are relatively old. Finally, in this case the measurement of Y_4 may be interpreted as an indication of the reasonably well chosen transfer prices, which are usually derived from market prices.

The measurement of productivity variation in the pulp industry casts doubts on the infinite growth of economies of scale in pulp production. Because of the calculation procedure, some of the weights in productivity indices may not necessarily be appropriate to aggregate inputs in two successive plants applying different production process. The robustness of the result, particularly the level of productivity measures in chemical pulp mills, can be interpreted as an indication of the independence of alternative indices from the weights used.

423. Paper Mills

The two-factor physical volume-based productivity measure (Y_1) is relatively inconsistent, which is presumably mainly due to heterogeneous products by individual mills (Fig. 6). Observations 1 and 6 represent wood-free printing and writing paper, observations 2 and 7 mechanical pulp-based folding boxboard, observations 3 and 9 sack kraft, observation 4 household and sanitary tissue, observations 5 and 10 to 12 wood-containing printing papers, and observation 8 solidboards made from kraft pulp.

Productivity is generally growing together with plant size, but product mix blurs the trend. Comparison within each product group supports the assumption on size-productivity relationship with the exception of the very largest mills. The same holds true for the physical output-based three-factor productivity (Y_3), although its growth tendency is slower and variation much less extensive than that of Y_1. The productivity range in

Paper Mills is almost as wide as in Pulp Mills as the highest observation equals five times the productivity level in the smallest mill.

The value-based measures behave somewhat differently from the physical output-based indicators. In some cases, such as household and sanitary tissue, low productivity measured in terms of physical output is compensated for by high value-based productivity. On the other hand, high Y_1 and Y_3 in large mills producing wood-containing papers is not followed by high values in Y_2 or Y_4.

The two-factor Y_2 varies much more widely than the respective three-factor measure, Y_4, although changes between successive observations are almost always to the same direction. In Y_4 a systematic upward tendency can be seen in spite of the declining performance of the largest mills. It is apparent that any productivity analysis on paper production should first separate the impact of product mix before looking into plant size or other factors. Y_4 continues to have the smallest standard deviation and this three-factor output value-based measurement apparently best evens out technological differences by plants compared to the other indicators.

424. Conclusions

It is apparent that the measurement of total productivity is very sensitive to the choice of output and input variables. There is no best way to measure total productivity as various indicators yield different information. At the process level total productivity measured in terms of physical volume-based output can be meaningfully analysed but, if a branch is composed of heterogeneous processes, value-based output indicators yield more meaningful results. This conclusion diverts from the general recommendation in literature that physical volume measures should be preferred in productivity analysis.

The ordering of observations by plant size in terms of annual production capacity is not necessarily the most meaningful way to arrange data in the branches studied. There is least evidence in Sawmills, where the products are more homogeneous than in Pulp and Paper Mills. It is possible that the economies of scale in this industry do not behave continuously but discreetly, presumably in the same step-wise way as the unit investment costs. On the other hand, it is possible that the measurement result in Sawmills can partly be explained by less fixed technology and greater management variation than in the pulp and paper industry. In general, the assumption of increasing economies of scale obtained support from total productivity indicators. However, the largest mills may not be the most efficient.

The productivity indicators which are measured in terms of value-based output deserve perhaps more scope for further analysis at branch level than those derived from physical output volumes. The greater instability of Y_2 compared to Y_4 may favour the latter because of the residual nature of net output in Y_2. In general, Y_4 appears to be least influenced by variation of technology.

The homogeneity of individual forest industry branches appears to be a doubtful assumption when analysing the economic relationships of production. More meaningful results could be obtained from data grouped by main processes. Product range and production technology can embarrass the interpretation of total productivity measurement. Without additional data on e.g. vintage structure, the results cast doubts on general studies on the role of plant size in the economic performance of the industry.

43. Comparison of Productivity and Profitability Indicators

This chapter attempts to evaluate to what extent partial and total productivity indicators provide the same information on the cross-section of the Finnish forest industries. A comparison is also made between productivity and profitability, trying to verify the meaningfulness of total productivity measures. The indicators included in the analysis are labour productivity (net output per employee hour, Y_L), capital productivity (net output per the adjusted capital stock, Y_K), materials productivity (value of materials input per gross value of production, Y_M), two-factor and three-factor output value-based productivity (Y_2 and Y_4), and gross margin of sales (net output minus labour cost divided by the gross value of production, r) as a measure of profitability.

The comparison of alternative indicators is made by means of Spearman's correlation coefficient r' which tests rank orders of two variables in a sample (branch). Spearman's coefficient was preferred to ordinary correlation coefficient because the data were subject to extreme observations and because we are here more concerned about the rank order of observations than the correlation between the values of the variables tested. Spearman's coefficient "wastes" information if continuous data are available but in this case, where measurement errors may be important, its use can be justified. The test values of Spearman's coefficient are dependent on the number of observations in the sample. In this case they vary from low Z = .39 in Sawmills to high Z = .59 in Paper Mills at the 5 per cent significance level. The coefficients are presented in Table 2.

The partial productivity indicators studied describe apparently quite different aspects of productivity and it would be wrong to replace one of them by another. The r's are low and in none of the cases significant. Even their signs are not consistent. Capital productivity appears to be a relatively good proxy for total productivity if measured by Y_2, as all the r's are significant. This relationship is strongest in Sawmills which may be explained by the larger relative variation of unit capital consumption compared to the other branches studied. In Pulp Mills labour productivity also obtains a significant Spearman's coefficient with Y_2. The materials input is not incorporated in the measurement of Y_2, which may explain why Y_M produces quite different information on the productivity ranking of observations. Y_M, which is measured as the inverse of productivity ratio, appears to describe a particular aspect of productivity as it obtains significant correlation coefficients only with Y_K. In spite of the materials intensity of the forest industries there is only a weak correlation between Y_M and the total productivity indicators. The measurement of Y_M may not have been successful.

Chapter 42. already suggested that Y_2 and Y_4 provide somewhat different information on total productivity. Their r' further confirms this conclusion as only in Sawmills does the correlation coefficient obtain a significant, even though relatively low value.

The profitability indicator correlates strongly with the two-factor productivity measure Y_2 which indicates that they produce largely similar information on the ranking of plants. Profitable plants have also good two-factor profitability. Y_4 does not obtain a significant coefficient in this comparison, and therefore it apparently describes other aspects of plant efficiency than does the other two. The reason may lie in the measurement of materials input in Y_4. If measures could be found which could better describe the pure volume aspect of materials input, it is possible that the resulting productivity indicator would match more closely to the ranking by Y_2 or gross margin. It is interesting to note that profitability and capital productivity have significant Spearman's coefficients in Sawmills and Paper Mills, while in Pulp Mills significance is obtained for labour productivity. Capital productivity appears to be

Table 2. Spearman's Correlation Coefficients for Productivity and Profitability Indicators

		Y_L	Y_K	Y_M	Y_2	Y_4
Sawmills						
	Y_K	–.248				
n = 29	Y_M	–.355	–.290			
$Z^{1)}$ = .37	Y_2	.053	.918	–.411		
	Y_4	.595	.305	–.170	.541	
	r	.046	.768	–.461	.822	.335
Pulp Mills						
	Y_K	.380				
n = 14	Y_M	–.235	.213			
Z = .54	Y_2	.569	.644	–.279		
	Y_4	.547	.244	–.178	.240	
	r	.763	.341	–.490	.798	.376
Paper Mills						
	Y_K	.545				
n = 12	Y_M	.434	–.049			
Z = .59	Y_2	.336	.748	–.462		
	Y_4	.643	.636	.280	.552	
	r	.434	.706	–.399	.937	.552

1) $Z = \frac{r'}{\sigma_{r'}} = r'\sqrt{n-1}$ (Koutsoyiannis 1978, 96–97)

a powerful indicator incorporating much of the variation in profitability and total productivity.

It is concluded that the indicators compared in this chapter produce information on the different aspects of efficiency and therefore the use of all of them is justified. The meaningfulness of total productivity indicator Y_2 can be verified by its correspondence with the chosen profitability indicator, while Y_4 should at least have a better measurement basis before similar conclusion can be reached. As there are a wealth of possible profitability indicators which could be used in the comparison, quite different results could be expected if they were used.

5. CROSS-SECTION ESTIMATION RESULTS

51. Production Functions

This chapter presents the estimation results of average neoclassical production functions in the Finnish forest industries based on the cross-section observations in 1974. Both individual branch data and pooled data by branch groups are used. In the analysis, alternative variable measurement is first reviewed in the CD environment. The properties of the average CD function are then evaluated and assumptions on the elasticity of substitution are gradually relaxed when less restrictive functions are estimated. Finally, biases and their consequences are evaluated. The significance of the parameter estimates is discussed at the five per cent risk level.

511. CD Function

Chapter 42. demonstrated the importance of the choice of output (and input) variables for productivity measurement. Table 3 indicates how estimation of the CD function is influenced when the capacity levels and the actual values of the variables are used, and when alternative output measures are tried.

Estimation appears to be relatively insensitive to the choice between the capacity-based variables and their actual volume-based counterparts (functions 1 and 2 in Table 3). The rate of capacity utilization does not appear to affect conclusions significantly, as illustrated by the following; in general, the sings of the parameters are similar, and differences in the corrected multiple correlation coefficient ($\bar{R}^2$) are relatively small. The conclusions are more valid for the pulp and paper industries than for the mechanical wood industries.

In the mechanical wood industries, the goodness of fit of the two-factor CD model improves when physical production volume measures, rather than capacity measures, are used as output indicators.

In the pulp and paper industries capacity is better explained by L and K than physical output. In the capacity-based models the explanatory variables are the number

Table 3. Output and Factor Measurement in Two-factor CD-environment

Branch	b_1 1	b_1 2	b_1 3	b_2 1	b_2 2	b_2 3	$\bar{R}^2$ 1	$\bar{R}^2$ 2	$\bar{R}^2$ 3	F 1	F 2	F 3
Sawmills	.9469	.8579	.9545	.1215	.1965	.1886	.9302	.9610	.9696	187.62***	346.12***	430.69***
	(.2284)	(.1455)	(.1371)	(.1431)	(.0888)	(.0837)						
Mechanical Wood Industry	.0382	–.5915	.6694	.5205	.9604	.3595	.5145	.5539	.9427	22.20***	25.83***	321.51***
	(.3654)	(.3465)	(.1179)	(.2307)	(.2207)	(.0751)						
Pulp Mills	.4420	.3576	.7032	.2063	.2462	.2985	.6645	.6256	.8996	13.87***	11.86**	53.77***
	(.5339)	(.5973)	(.4308)	(.3833)	(.4444)	(.3205)						
Paper Mills	–.6425	–.2988	.4787	1.6927	1.3171	.4180	.7895	.6309	.5229	21.63***	10.40**	5.88*
	(.3715)	(.4508)	(.3946)	(.3118)	(.3899)	(.3412)						
Pulp and Paper Industry	–.3058	–.1574	.6290	.8112	.6817	.3307	.6337	.6005	.8311	22.62***	19.79***	59.40***
	(.3717)	(.3751)	(.3038)	(.2787)	(.2926)	(.2371)						
Forest Industry	.2341	–.0912	.3944	.3506	.5269	.5034	.6034	.5141	.9200	51.22***	35.91***	374.09***
	(.2171)	(.2485)	(.1176)	(.1215)	(.1487)	(.0698)						

Functions:

1. $\ln C = a + b_1 \ln L + b_2 \ln K_W$
2. $\ln Q_F = a + b_1 \ln L_H + b_2 \ln K_U$
3. $\ln Q_N = a + b_1 \ln L_H + b_2 \ln K_U$

of employees and the weighted replacement value of machinery, equipment and structures. In the physical output-based models total employee-hours and the weighted replacement value of the capital stock adjusted to capacity utilization ratio have been used as input indicators. It is more flexible to adjust labour for different output levels in the mechanical wood industries than in the pulp and paper production where the rules of vacancy requirements and labour pools are more strict. The labour turnover statistics also support this conclusion. The average annual rates of quits have been 32.1 per cent in mechanical wood industries and 22.2 per cent in pulp and paper industries during 1975–1979 (Suomen . . . 1979).

The two branch groups were undergoing somewhat different stages of the business cycle in 1974. The pulp and paper industries were operating at a very high rate of capacity utilization, while the production of sawnwood and wood-based panels had already passed the peak of the cycle. The more capital-intensive pulp and paper industries may plan the use of their resources more in relation to the capacity level of output than the anticipated production while in the mechanical wood industries it is less indispensable to reach the full utilization of the capacity thus allowing more flexibility in input adjustment. This can be seen in the goodness of fit of the model which is better in the mechanical wood industries when actual output-based variables are used, while in pulp and paper production capacity-based models perform better.

Capacity can be defined with less ambiguity in pulp and paper mills than in sawnwood or wood-based panel production. In particular, the capacity of sawmilling industry is difficult to define (Rinkinen 1966) and a part of the data used here is obviously erroneous. In the pulp and paper industry, which is typically working continuously in three shifts, the difficulties to define the capacity output are mainly related to the constancy of product mix over time and the standards of various technical efficiencies. It should, however, be noted that the differences in the explanatory capacity between the models with and without utilization rate are not substantial with the exception of Paper Mills, where $\bar{R}^2$ was reduced from .79 with capacity measures to .63 when actual physical output was used. Førsund and Hjalmarsson (1979, 83) also found that in the Swedish particle board industry adjustments for capacity utilization had very little impact on the obtained values of the marginal elasticities and scale parameters.

The estimation results of the net output-based model (function 3 in Table 3) are distinctive from those discussed above. The signs of parameter estimates behave now according to hypotheses, and apart from one branch (Paper Mills) multiple correlation coefficient improves. In general, an output variable based on value added-type measures appears to yield better results in the two-factor CD models than do physical volume-based indicators. The rate of capacity utilization should be adjusted in input measurement.

In the physical output measures quality is disregarded. This is justified when outputs are relatively homogeneous over establishments. In forest industries, the production of main pulp grades or sawmilling could perhaps be considered sufficiently homogeneous in this respect. However, the technical concepts of mills can vary even in these branches to such an extent that it makes physical volume-based measures uninteresting in this kind of comparison. The variation may be due to process characteristics and horizontal or vertical integration. The estimation results above support this assumption.

The rate of returns can be estimated from the labour productivity formulation of the CD function (formula 2.3). The results (Table 4) would indicate approximately constant returns to scale in Mechanical Wood Industry and Pulp Mills but the scale coefficient is not significant. This is presumably more plausible in pulp production than in the pooled observations of sawmilling and wood-based panels production. Sawmilling is the only branch of forest industry where increasing returns can be identified ($b_2 > 1$ in function 1 Table 4.) Paper Mills appear to have the lowest and decreasing returns to scale but the coefficient is not significant. The largest mills in this branch produce such bulk grades as newsprint and other wood-containing papers, kraft linerboard, sack kraft, etc., while the smaller units concentrate on wood-free printings and writings, household and sanitary tissue and specialities. This may partly explain, why value added-type output measure can yield decreasing returns to scale in a cross-section over these relatively heterogeneous main products. The decreasing returns to scale in the Forest Industry, even though not significant, may be partly due to the composition of the sample. In this pooled branch the small and medium-sized production units are mostly sawmills and wood-based panel plants, while the larger mills belong to the pulp and paper industry. The result would, however, support the earlier conclusion that the rate of returns is higher in the mechanical wood industries than in the pulp and paper production.

In Table 4 the parameter estimate of capital input is less disturbed by multicollinearity than in Table 3 but its value does not correspond well to the calculated shares of capital (last column in Table 4). The latter indicator is influenced by the exceptionally good financial results in 1974 and it may, therefore, exaggerate the long-term level of capital's income share in the Finnish forest industries. The parameter estimate of capital input is significant at the five per cent level in Sawmills, Mechanical Wood Industry and Forest Industry and its magnitude generally changes in accordance with the hypotheses, i.e. higher capital intensity yields higher parameter estimates. In these three branches the fit of the cross-section model is relatively good, the model explaining 47 to 57 per cent of the labour productivity variation when measured by $\bar{R}^2$ and the F-value is significant at the 0.1 per cent level. The results of the three branches of the pulp and paper production are quite different. Neither the parameter estimate of capital input nor the scale coefficient nor the F-value is significant. The multiple correlation coefficients in the pulp and paper industries remained marginal, indicating that hardly any of the variation in labour productivity across plants has been explained. Although the variance of labour productivity is smaller than that of output, the CD function explains proportionally less of this variance than of the respective output variance (cf. Table 3).

Griliches and Ringstad (1974, 64) and Bosworth (1976, 103–104) found the same reduction in the multiple correlation coefficient when the CD function (2.2) was transformed into (2.3). Only if a good fit is obtained for all alternative formulations, can the model be said to have a high explanatory power. In this study, we are more concerned about productivity variation than about the explanation of output variation, and therefore improvement of the labour-productivity formulation of the CD function is important here. This form has

Table 4. Estimation of CD and CES Production Functions

Branch	b_1		b_2		b_3	$\bar{R}^2$		F		Capital's income share [1]
	1	2	1	2	2	1	2	1	2	
Sawmills	.1886	.1998	.1431	.1379	–.0196	.5682	.5523	19.43***	9.38***	.6599
	(.0853)	(.0962)	(.0640)	(.0680)	(.0725)					
Mechanical Wood Industry	.3595	.3606	.0290	.0284	–.0031	.4719	.4577	18.87***	12.25***	.6577
	(.0761)	(.0821)	(.0582)	(.0610)	(.0795)					
Pulp Mills	.2985	.3561	.0017	–.0037	.1539	..[2]	..[2]	.79	.51	.7314
	(.3348)	(.3934)	(.1473)	(.1547)	(.4384)					
Paper Mills	.4181	.4158	–.1032	–.1092	.4712	..[2]	..[2]	.83	.53	.8985
	(.3597)	(.3791)	(.2670)	(.2820)	(1.4536)					
Pulp and Paper Industry	.3307	.3674	–.0404	–.0276	.2363	..[2]	..[2]	.99	.75	.8414
	(.2422)	(.2541)	(.1093)	(.1131)	(.4143)					
Forest Industry	.5034	.5079	–.1022	–.0994	.0322	.4938	.4875	33.19***	21.93***	.8045
	(.0703)	(.0714)	(.0587)	(.0594)	(.0688)					

Functions:

1. $\ln Y_L = a + b_1 \ln K/L_2 + b_2 \ln L_H$
2. $\ln Y_L = a + b_1 \ln K/L_2 + b_2 \ln L_H + b_3 [\ln (K/L_2)]^2$

1) $(Q_N - W) / Q_N$, where Q_N is net output and W total labour cost

2) Not reported because R^2 was so low that $\bar{R}^2$ became negative

the advantage that it avoids the tendency of purely scale effects (i.e. large industries tend to employ large amounts of capital and labour) swamping effects of variations in labour and capital on the output of industries of a given size (Bosworth 1976, 104).

All the CD models above and the CES models presented in the following chapter have been estimated with a constant term. Its values have not, however, been reported because they are almost invariably insignificant. This may be interpreted as the non-existence of an autonomous trend factor related to plant size which would be important for analysing labour productivity variation.

512. CES Function

It is possible that the poor results of the pulp and paper industries are due to a too restrictive production function. The estimation results of the Kmenta CES production function (formula 2.6) are not, however, better than those of the CD model (function 2 in Table 4). In none of the branches studied was the parameter estimate of the square term significant and they would therefore hardly yield reasonable estimates of elasticity of substitution. The results do not necessarily indicate the failure of the CES function in the Finnish forest industries but it is possible that the samples, perhaps with the exception of Sawmills, were not large enough and did not have sufficient variation in capital and labour inputs to allow b_3 to be estimated with the necessary precision.

The magnitude of elasticity of substitution (σ) can be evaluated by various approaches. Interpretation of the elasticity of substitution in an average production function is vague and therefore only the marginal productivity relation of labour or the ACMS relation (function 2.5) is estimated here to assess the possible magnitude of σ (Table 5). When labour productivity is explained by the average wage rate (including fringe benefits) the fit of the model is better in the mechanical wood industries ($\bar{R}^2 > .43$) than in the pulp and paper industries ($\bar{R}^2 < .25$). The same kind of difference in fit was already found in the CD functions. The estimated σ has relatively high values ranging from low 1.85 to 1.86 in Sawmills and Mechanical Wood Industry to high 2.86 in Pulp and Paper Industry. The value of elasticity of substitution appears to correlate positively with capital intensity. The result supports the assumption that growing capital intensity makes it more and more difficult to substitute capital for labour.

Table 5. Estimation of ACMS Relation and VES Function

Branch	b_1			b_2		$\bar{R}^2$			F		
	1	2	3	2	3	1	2	3	1	2	3
Sawmills	1.8543	.8335	1.0947	.1401	.2066	.5526	.5857	.6125	35.57***	20.79***	21.79***
	(.3109)	(.6474)	(.4711)	(.0788)	(.1011)						
Mechanical Wood Industry	1.8621	.8320	.8545	.1749	.2805	.4355	.5308	.5440	31.85***	23.62***	23.74***
	(.3299)	(.4577)	(.4442)	(.0586)	(.0921)						
Pulp Mills	2.2682	1.5376	2.5588	.1808	.3577	.2406	.3317	.4701	5.11*	4.23*	5.74*
	(1.0025)	(1.0426)	(.8471)	(.1114)	(.1569)						
Paper Mills	2.6326	.5112	–.8871	.2855	.8830	.0490	.2336	.4048	1.57	2.68	3.82
	(2.1032)	(2.2102)	(2.2003)	(.1546)	(.3807)						
Pulp and Paper Industry	2.8581	1.7596	2.5658	.1944	.3024	.2397	.3347	.3365	8.88**	7.29**	6.55**
	(.9591)	(1.0380)	(.9095)	(.0924)	(.1616)						
Forest Industry	1.9715	.9957	1.6022	.2256	.0828	.4654	.5724	.4719	58.46***	45.16***	29.53***
	(.2578)	(.3292)	(.4864)	(.0543)	(.0928)						

Functions:

1. $\ln Y_L = a + b_1 \ln w$
2. $\ln Y_L = a + b_1 \ln w + b_2 \ln C$
3. $\ln Y_L = a + b_1 \ln w + b_2 \ln K/L_l$

Apart from Paper Mills the wage rate's parameter estimates are significant. It should be noted that both the dependent variable and the explanatory variable include some quality variation of output and labour input. The wage rate refers to average total labour input. In the Finnish forest industries wage levels are agreed through national collective bargaining, which may then be adjusted to local conditions in negotiations at individual mills. The observed differences in w include both this variation and the effect of different compositions of labour input influencing the average cost of employee hour. The estimation result could, however, support the assumption that the prevailing wage rate variation may be a significant factor for explaining labour productivity differences in spite of its partly institutional nature. More interesting results could possibly be obtained if the estimation were carried out over countries or a large number of branches to allow a wider variation of wage rate.

The estimation results of the ACMS relation do not support the assumption that elasticity of substitution equals one. Its non-constancy has been tested by two VES functions where either plant capacity (C) or the K/L ratio have been added to the marginal productivity equation (functions 2 and 3 in Table 5). Because of multicollinearity w's parameter estimates are now less often significant. With one exception, a better fit of the model is obtained by the K/L ratio-based VES version but differences compared to the capacity version are not very important. The branches of the mechanical wood industries continue to enjoy higher multiple correlation coefficients and more significant F-values than the pulp and paper industries. The results support the assumption on non-constant elasticity of substitution in the average production function for the Finnish forest industries but they remain inconclusive.

Additional tests about the form of the production function were carried out by estimating the translog production function or a general second order polynomial (formula 2.8) which does not include constant elasticities or assume homotheticity. In general, the translog function did not represent any improvement compared to the Kmenta form. The hypothesis of non-homotheticity cannot be rejected in this analysis.

513. Dummy Variables

Until now the assumption on constant elasticity of substitution has referred to the entire branches or branch groups. Were larger samples available, estimations could have been carried out by process, plant size and integration groups within individual branches. As this was not possible the non-constancy of the elasticity of scale was further investigated through the introduction to the CES form of dummy variables describing the plants' characteristics related to process, size and integration. The estimation results of the enlarged ACMS relation are presented in Table 6 which reports the parameter estimates of dummy variables when added to the function one at a time. All of these regressions give essentially the same estimates of σ (w's coefficient) and are not, therefore, reported here.

In Sawmills, none of the dummies' parameter estimates are significant. This can be interpreted such that neither the main process (D_{11} or frame sawing compared to other methods) nor further conversion (D_{31}) are sources of non-homotheticity in the existing industry. In Finnish sawmills in 1974, with few exceptions, further conversion had limited importance compared to the production of rough sawnwood and therefore it may not sufficiently reflect in the overall input-output relationship. Were secondary converting operations important, the result might have indicated greater significance of D_{31}'s parameter estimate. The role of plant size (D_{2i}) is not clear because in spite of the insignificance of the parameter estimates their values indicate that production conditions may change essentially between the largest sawmills (more than 100 000 m^3 per year) and the others. When the size dummies were tried in the CD environment, this phenomena was confirmed by significant parameter estimates for D_{24}. The dummy variables do not contribute essentially to the fit of the ACMS relation in the sawmilling industry.

The results for Pulp Mills would indicate that mechanical and sulfite pulp mills do not obtain a significant parameter estimate for the process dummy (D_{1i}). The sulfate pulp plants appear to have clearly different production relationships from the others, which may not only reflect different process rela-

Table 6. Dummies in ACMS Relation

Dummy variable	Sawmills	Pulp Mills	Paper Mills	$\bar{R}^2$ Sawmills	$\bar{R}^2$ Pulp Mills	$\bar{R}^2$ Paper Mills
D_{11}	–.0326	–.1760	.2542	.5363	.2338	.0390
	(.1405)	(.1861)	(.2686)			
D_{12}	. .	–.1752	.5561	. .	.2435	.3548
		(.1713)	(.2321)			
D_{13}	. .	.3361	–.6286	. .	.4284	.6450
		(.1511)	(.1490)			
D_{21}	–.0346	.2263	–.8152	.5364	.2169	.4516
	(.1412)	(.2835)	(.2823)			
D_{22}	–.0769	–.3381	.0618	.5446	.4565	. .[1)]
	(.1057)	(.1408)	(.2671)			
D_{23}	–.0055	.2890	.3584	.5354	.3572	.1305
	(.0932)	(.1620)	(.2574)			
D_{24}	.1733	. .	. .	.5636	. .	. .
	(.1336)					
D_{31}	.0500	.2150	–.0136	.5410	.2488	–.0563
	(.0886)	(.2021)	(.2545)			

1) Not reported because R^2 was so low that $\bar{R}^2$ became negative

tionships but also different vintage structure. When D_{1i} was tried in the CD environment the results were otherwise similar but D_{13} did not obtain a significant parameter estimate. In 1974 most of the sulfite mills were relatively old compared to sulfate mills. The age structure hidden in the process variable may be the plausible explanation for the estimation results obtained in the ACMS relation. The only significant parameter estimate for size dummies (D_{2i}) in Pulp Mills is obtained for plants with a capacity of 50 001 to 150 000 tons per year. In addition, the signs of the size dummy parameters support the assumption of non-homotheticity as regards plant size in the pulp industry. The dummy variable differentiating integrated and market pulp mills (D_{31}) did not obtain a significant parameter estimate. It has, however, been demonstrated by Eklund and Kirjasniemi (1969) that integration benefits are important in the pulp industry. The estimation result may be partly explained by the fact that many integrated mills also have pulp drying machines since they sell part of their produce as market pulp. On the other hand, the internal methods and principles of recording costs and revenues in integrates vary and this may disturb the results.

In Paper Mills it is apparent that the product range as illustrated by the main product (D_{1i}), is a significant factor determining the rate of returns. Important improvement in the goodness of fit of the model is obtained when D_{12} and D_{13} are added to the ACMS relation. Also the plant size (D_{2i}) appears to be a source of non-homotheticity, particularly with regard to the smallest mills (capacity 50 000 tons per year or less) compared to the rest of the industry. The main integrated furnish component is not a significant factor, if measured in terms of the dummy variable used (D_{31}).

It can be concluded that both the pulp and paper industries appear to be composed of so heterogeneous groups of plants that the properties of their (average) production function do not meet the assumption of constant returns to scale and sources of non-homotheticity may be process or product range, plant size, or integration. Similar results were obtained when the dummy variables were tried in the CD environment, which indicates robustness of the estimation results. If the assumption of constant returns to scale is implied by the production function under study the analysis has to be carried out at a more disaggregated rather than branch level.

514. Bias

There are a number of possible reasons why the fit of the production functions presented in this chapter remains low in many cases. The error term may be due to different vintages, variations in factor prices, and different expectations about future factor price ratios. Furthermore, because of different product specifications, chosen technology and other similar reasons there are variations in capital-labour ratios, scale, etc. within individual industries (cf. Griliches-Ringstad 1971, 15). These sources of bias are due to the simultaneity problem, because random changes in output may be related to changes in labour and materials inputs or even in capital input. The estimations were made for average production functions which, by definition, are fictious (Chapter 212.) and therefore *a priori* erroneous for individual production units. Finally, based on a number of field checkings it is reasonable to assume that there may be important measurement errors in the Finnish industrial statistics, particularly with regard to the capital measure applied.

Griliches and Ringstad (1971, 92–103) have derived the explicit formulae for biases due to simultaneity, measurement errors, and quality and price differences. These formulae are used as the basis in the following. The effect of quality and price is not investigated here because the industries studied are narrowly defined. The starting point is the simple simultaneous equation model

$$(5.1) \quad \ln Q = \alpha \ln L + \beta \ln K + u$$

$$(5.2) \quad \ln \left(\frac{Q}{L}\right) = \sigma \ln w + v,$$

where Q refers to output, L to labour input, K to capital input, w to real wage rate and u and v are error terms. The model is composed of the CD function (5.1) and the ACMS relation (5.2). Intercept terms are omitted as all the variables are measured as deviations from their means. Constant returns to scale (h = 0) and parameters equal to the observed factor shares are assumed. First, it is examined whether simultaneity could have been the reason for the observed economies of scale. The bias of economies of scale can be written

$$(5.3) \quad \text{bias } \hat{h}_1 = \left[-d_1 + d_2 b_{wK}\right] R,$$

where d_1 is h estimated by formula (2.3), d_2 is the estimated σ from formula (2.5), b_{wK} is the regression coefficient of the wage rate on the capital measure, and

$$R = \frac{\sigma_u^2}{\sigma_u^2 + \sigma^2 \sigma_w^2 \left(1 - r_{wK}^2\right) + \sigma_v^2}$$

where r^2 is the regression coefficient between wage rate and capital, σ_w^2 is the variance of wage rate, and σ_v^2 is derived from function (5.2). σ_u^2 estimated from formula (5.1) would be biased and therefore it is calculated as

$$\sigma_u = \frac{1-\alpha}{1+\alpha}\left[\sigma_{Q/L}^2 - \beta^2 \sigma_K^2 - \alpha^2 \sigma_L^2 - 2\,\alpha\,\beta \text{ Cov} \ln K \ln L\right]$$

where r_{wK}^2 is the regression coefficient between variables. Because the estimation results of formula (5.1) did not yield constant returns to scale (Table 5.2) factor shares are calculated and used instead of the estimated factor elasticities α and β. Labour's income share is

$$(5.4) \quad s_L = \exp\left(\bar{W} + \frac{1}{2}\,\frac{n-1}{n}\,\sigma_w^2\right),$$

where W is the observed share of labour cost in the value of output. The income share of capital s_K equals $1 - s_L$.

It can be assumed that among the variables used, capital input is subject to the largest measurement errors. The possible bias in the rate of returns estimate originating from random errors in the capital measure, can be written

$$(5.5) \quad \text{bias } \hat{h}_{21} = \lambda\, s_K \frac{b_{KL} - 1}{1 - r^2_{(K/L),\,L}}$$

where λ is the fraction of error variance in the total measure of the observed capital measure, b_{KL} is the regression coefficient of capital measure on labour input, and $r^2_{(K/L),\,L}$ is correlation coefficient between the capital-labour ratio and labour input. In this case it was crudely assumed that half of the variance of the K/L ratio was due to measurement errors.

Another way to estimate the bias in the economies of scale parameter at a given λ is

$$\text{(5.6)} \quad \text{bias } \hat{h}_{22} = (s_K - b_1)(b_{KL} - 1)$$

where $\hat{b}_1$ again refers to function (2.3).

The estimated bias in the economies of scale parameter has been reported in Table 7. In general, the bias is negative indicating that the rate of returns could be higher than estimated. Apart from the heterogeneous Paper Mills, increasing returns could be assumed for all the branches studied. The bias appears to be most important in Pulp Mills which would have the highest rate of returns in the forest industries if the bias $\hat{h}_1$ estimates are accepted. The estimated bias originating from the measurement of capital is also negative except in one case. $\hat{h}_{21}$ and $\hat{h}_{22}$ yield relatively similar results except in the pooled Forest Industry. Their size is relatively small except in Sawmills and Forest Industry. The result is plausible as the sawmilling industry is characterized by a large number of independent small and medium-sized companies which have the least developed recording systems for such inputs as capital.

The least squares bias of the CD and CES production functions was evaluated by estimating reversed regressions, i.e. using labour or capital variables as the variables to be explained (cf. Korpelainen 1967, 74–77). The equations were then solved for output variables. The reversed CD function yielded relatively inconsistent parameter estimates compared to the non-reversed function. Based on the results it appears that the measurement error may be more serious in labour input than in the capital variable, particularly in the pulp and paper branches. The reason for this error may be partly due to the treatment of joint maintenance and other departments in integrated pulp and paper mills. Estimation of the reversed ACMS relation indicated that the original estimates of elasticity of substitution appear to be influenced by least squares bias.

Table 7. Bias in Economies of Scale

Branches	$\hat{h}$[1]	bias $\hat{h}_1$	bias $\hat{h}_{21}$	bias $\hat{h}_{22}$
Sawmills	.1431	−.0767	−.1558	−.1418
Mechanical Wood Industry	.0290	−.1212	−.0804	−.0445
Pulp Mills	.0017	−.5007	−.0441	−.0376
Paper Mills	−.1032	.0083	−.0383	−.0796
Pulp and Paper Industry	−.0404	−.1972	−.0323	−.0527
Forest Industry	−.1022	−.2054	−.1426	.0074

[1] Source: Table 4.

It can be concluded that the production function estimations presented in Chapters 511. to 513. may be subject to various sources of bias, the most frequent being simultaneity and measurement errors in variables. The effect of bias has presumably been the underestimation of the economies of scale parameters. The bias may be of such magnitude that it influences the conclusions drawn from the estimation results. There are also other possibilities to investigate bias, such as comparing the estimation results of partial samples, but the methods chosen were deemed most convenient and applicable for this study.

52. Productivity Models

In this chapter an attempt is made to explain the productivity variation in the Finnish forest industries in 1974. Single equation models derived from the formula (2.16) are estimated for factor productivities and total productivity. The models presented in this chapter have been chosen from a large number of estimations made with different variable combinations. Preference has been given to models which, in all the branches studied, tend to give significant parameter estimates, which have the smallest error variances, and which give a good fit. As these criteria tend to be contradictory and individual branches may yield different kinds of results, it is evident that the choice of models has been a compromise.

The correlation coefficients of the main explanatory variables used in the estimation of productivity models are presented in Appendix 2 for the evaluation of multicollinearity. Productivity models are estimated without a constant term because, in general, it did not reach significant values in production functions. Furthermore, all variables were measured around their geometric means.

521. Labour Productivity

Many of the production functions discussed in Chapter 51. rendered information on factors influencing labour productivity. Some complementary estimations are presented in Table 8. Within the available variable data the most important explanatory factors for labour productivity variation are capital-labour ratio and plant size. Because K/L and C are correlated, their exact importance is difficult to establish. It is, however, apparent that high labour productivity tends to prevail in large plants which also use a lot of capital per labour input. The K/L ratio used in the labour productivity models (K/L_1) is not adjusted for capacity utilization with regard to capital input. The choice between the unadjusted and adjusted ratio was made on the basis of their explanatory capacity in the model. The partly rigid nature of labour input also supports the choice.

In the mechanical wood industries the parameter estimates of the K/L ratio, which can be interpreted as elasticities, range from .20 to .24 and those of plant size from .14 to .18. A certain increase in labour productivity would, in relative terms, need a larger increase in capital-labour ratio compared to plant size. Though lacking conclusive evidence, this relationship may be stronger in the pulp and paper production than in the mechanical wood industries.

The output quality variable q_1 obtained a positive parameter estimate in Sawmills and Mechanical Wood Industry. High labour productivity appears therefore to be related to the high degree of conversion. In the pulp and paper branches the coefficient was not significant which may be due to the fact that in different branches the variable describes product quality from different viewpoints. Transfer pricing of pulp in integrated pulp and paper plants may explain why the parameter did not obtain significant values in Pulp Mills and Pulp and Paper Industry. In these two branches the model was expanded to include labour price and quality variables, i.e. average salary and wage rate (w) and the

Table 8. Labour Productivity Model

Branch	b_1	b_2	b_3	b_4	$\bar{R}^2$	F
Sawmills[1]	.2081 (.0768)	.1432 (.0435)	.6921 (.1684)		.7673	47.16***
Mechanical Wood Industry[1]	.2379 (.0685)	.1803 (.0434)	.3849 (.2005)		.6525	38.56***
Pulp Mills[2]	.5664 (.2335)	.1009 (.1454)	2.7604 (1.0030)	−.2527 (.0931)	.6338	8.50**
Paper Mills[3]	.5617 (.2039)	−.6398 (.2382)	−.4437 (.1726)		.7418	16.80***
Pulp and Paper Industry[2]	.2517 (.2206)	.2050 (.1244)	1.8761 (.9973)	−.2280 (.1042)	.4356	7.43**
Forest Industry[1]	.1204 (.0545)	.2406 (.0473)	−.5885 (.1491)		.6377	59.09***

Functions:

[1] $\ln Y_L = b_1 \ln K/L_1 + b_2 \ln C + b_3 \ln q_1$

[2] $\ln Y_L = b_1 \ln K/L_1 + b_2 \ln C + b_3 \ln w + b_4 \ln L_S$

[3] $\ln Y_L = b_1 \ln K/L_1 + b_2 \ln q_2 + b_3 \ln D_{21}$

share of salaried personnel in the total labour input (L_S). As a result the standard error of the model was reduced, particularly in Pulp Mills, and the two additional explanatory variables proved to be significant. The sign of the labour unit price parameter continues to be positive (cf. Table 5) supporting the assumpion that high salary and wage rates are related to high labour productivity. The parameter estimate of L_S is significantly negative implying that several organization levels and extensive staff functions do not necessarily improve overall labour productivity. The conclusion refers here only to Pulp Mills and Pulp and Paper Industry, but similar evidence was also obtained for those branches where L_S had sufficient variation to be significant.

In Paper Mills, plant size was replaced by the size dummy D_{21} and the output quality variable q_2 was used instead of q_1. The resulting model has a good explanatory capacity in spite of the relatively small number of observations (12); it does not suffer from serious multicollinearity; and all its parameter estimates are significant. Variable q_2 is an important contributor to labour productivity variation in Paper Mills, while in the other industries it fails to be significant.

The models tried explained relatively well the variation in labour productivity between branches. Mechanical wood industries and pulp and paper industries have somewhat different characteristics in this respect and therefore require different explanatory variables. Because of the role of plant size and capital-labour ratio, it appears that investment decisions have defined to a large extent the obtainable range of labour productivity. The results indicate indirectly that the latter variable tends to increase more rapidly than the former in relative terms.

522. Capital Productivity

The simple model with K/L, C, and q_1 as dependent variables, used for explaining labour productivity variation in the mechanical wood industries, also performed well for capital productivity (Table 9). To improve fit of the model both capital productivity and capital-labour ratio were measured adjusted to the capacity utilization ratio. In general, the higher the capital productivity, the less capital employed per labour input. The parameter estimate of K/L is always negative and significant in all branches but one (Paper Mills). Elasticity between the capital-labour ratio and capital productivity varies within the range $-0.78 \ldots -1.01$, the mechanical wood industries occupying the lower end and

Table 9. Capital Productivity Model

Branch	b_1	b_2	b_3	$\bar{R}^2$	F
Sawmills	−.8349 (.0567)	.1604 (.0371)	.6645 (.1655)	.9139	149.70***
Mechanical Wood Industry	−.7781 (.0707)	.1752 (.0469)	.4941 (.2034)	.7989	80.48***
Pulp Mills	−1.0086 (.3156)	.2563 (.1524)	−.0573 (.2824)	.4857	7.13**
Paper Mills[1)]	−.1101 (.3068)	.0895 (.1107)	−1.2457 (.3871)	.6856	12.99***
Pulp and Paper Industry	−.9924 (.2134)	.2693 (.0975)	−.3513 (.2144)	.5165	14.35***
Forest Industry	−.8060 (.0614)	.2058 (.0475)	−.5603 (.1445)	.7618	106.53***

Function: $\ln Y_K = b_1 \ln K/L_2 + b_2 \ln C + b_3 \ln q_1$
1) q_1 replaced by q_2

the pulp and paper branches the higher end. Paper Mills are an exception because q_2 was used instead of q_1, and if the model had been estimated with q_1 the parameter estimate of K/L_2 would have been −.79 in this branch. The significance of the capital-labour ratio to capital productivity, may imply that it can be used as a planning criterion also at micro-level supporting decisions about e.g. plant size. On the other hand, in the above analysis the K/L ratio is likely to be affected more by vintage than plant size, at least in pulp and paper production, which may signify limitations in the interpretation of results.

On the other hand, large mills tend to yield high capital productivity but the relationship is weaker than that for the K/L ratio. C obtains a significant parameter estimate in all branches excluding Pulp Mills and Paper Mills. The significant elasticities vary from low .16 . . . .18 in the mechanical wood industries branches to high .27 in Pulp and Paper Industry, where the size effect on capital productivity appears to be more important. The correlation coefficient between K/L_2 and C is not very high, and the range is narrow from low .46 in Paper Mills to high .63 in Pulp Mills (Appendix 2). The conflicting influence of plant size and capital-labour ratio on capital productivity is of particular interest, as capital is typically seen to be the scarcest resource, which should be used most efficiently. If, as it was concluded above, K/L ratio tends to increase more rapidly than C in the existing industry, there is apparently an optimum plant size, not necessarily the largest possible one, which yields the highest capital productivity. This size could be found by an additional study, but for planning purposes we would need *ex ante* information on these relationships between blueprint technologies.

Output quality q_1 obtains significant parameter estimates in all branches except Pulp Mills and Pulp and Paper Industry. Comparison with the model where only K/L_2 and C were independent variables revealed that q_1's contribution to the explanation of capital productivity variation is marginal. In the mechanical wood industries branches a high share of value added is positively correlated with capital productivity but in pulp and paper production the relationship is negative. In Paper Mills q_1 was again replaced by q_2. In fact, in this branch q_2 is the key variable which appears to explain significantly both labour and capital productivity; the higher the degree of "specialization", the higher the productivity. The same significance for q_2 was not obtained in the other industries. The quality of capital input as measured by the share of machinery and equipment in the total fixed capital may not have sufficient variation to contribute to capital productivity as it did not obtain significant parameter estimates in the model. The same may hold even more true with the price of capital input, which, however, was impossible to include at a meaningful level in this study. Other efforts to improve capital productivity models were not successful.

523. Materials Productivity

Materials productivity was measured here as the cost share of materials input in the gross value of output (Y_M) or the inverse of productivity ratio. The best results were reached by a model which included the labour-materials ratio (L/M), plant size (C) and output quality (q_2) as explanatory variables (Table 10). In general, the model performed relatively well in terms of the adjusted multiple correlation coefficient ($\bar{R}^2 > .50$) with the exception of Pulp Mills and Pulp and Paper Industry.

The labour-materials ratio obtains a significant negative parameter estimate over the whole sample. The greater amount of labour used per unit of materials input, the lower is the share of materials cost in gross value of output which can be interpreted to indicate possible limited substitution between labour and materials. The value of the elasticity coefficient is lower in pulp and paper production (.−15 . . . −.25) than in the mechanical wood industries (.−29 . . . −.53). The result is plausible as the latter branches are more labour intensive than the former.

In the mechanical wood industries and Forest Industry larger plants tend to have slightly lower materials-output ratios than smaller ones, as the parameter estimate of C is negative. Large sawmills tend to have sophisticated production planning systems for the purpose of maximizing the efficiency of utilization of available sawlogs, while

Table 10. Materials Productivity Model

Branch	b_1	b_2	b_3	$\bar{R}^2$	F
Sawmills	−.2884 (.0769)	−.0358 (.0154)	.6969 (.4263)	.5455	17.81***
Mechanical Wood Industry	−.5306 (.0554)	−.0848 (.0218)	1.6647 (.4810)	.7028	48.28***
Pulp Mills	−.2536 (.0912)	−.0389 (.0445)	.2329 (.2970)	.4437	6.18*
Paper Mills	−.1517 (.0633)	.0448 (.0341)	.2191 (.0861)	.6239	10.12**
Pulp and Paper Industry	−.2232 (.0608)	−.0329 (.0318)	.2165 (.1182)	.3733	8.45**
Forest Industry	−.3420 (.0425)	−.0760 (.0201)	.1933 (.1376)	.5040	34.54***

Function: $\ln Y_M = b_1 \ln L/M + b_2 \ln C + b_3 \ln q_2$

medium-sized and small units are less automated and therefore do not perhaps reach high materials productivity. The evidence in pulp and paper production is inconclusive, perhaps reflecting less dependence between plant size and materials productivity than in the mechanical wood industries. Output quality is significant only in Mechanical Wood Industry and Paper Mills. Only in the latter branch does it contribute essentially to the explanation of materials productivity variation based on comparison with the same model without q_2. The specialization variable gave, however, better results than q_1 which was generally used in the other productivity models.

Additional estimations were carried out by models with a physical volume-based measure as materials productivity indicator and average annual wood cost as input price indicator. These trials were not, however, successful perhaps because of the apparently large measurement error in wood consumption and cost variables. The analysis of materials input here remained limited but its further study could produce interesting results, were better and more comprehensive information available. Engineering data according to main processes, end products and plant size categories would possibly be necessary to enable meaningful analysis of materials productivity in forest industries.

524. Total Factor Productivity

Two total productivity measures calculated in Chapter 4 were selected for model estimation i.e. the two-factor net output-based Y_2 and the three-factor gross output-based Y_4. Total productivity indicators can be interpreted as residuals of an implicit production function (Chapter 22.) and, therefore, somewhat lower demands may be placed on estimation results here compared to those for the partial productivity measures discussed in Chapters 521. to 523.

The variation of the two-factor Y_2 was best explained by a model with plant size, capital-labour ratio and output quality q_1 (q_2 in Paper Mills) as explanatory variables (Table 11). The adjusted multiple correlation coefficient varied from .35 to .77 with the exception of Pulp Mills where the model only marginally accounted for productivity variation. In this branch the measurement error in value added may reflect unproportionally in the residual Y_2 High two-factor productivity is generally attained in large plants. The significant elasticity coefficient of plant size ranges from .12 to .26. The reliance of total productivity on plant size appears to increase with growing capital intensity. On the other hand, mills using small amounts of capital per labour input also tend to have high total productivity as the significant parameter esti-

mates of the K/L ratio are negative. Again, it appears that the contributing role of K/L ratio in total productivity variation increases with growing capital intensity. The elasticities are systematically higher than those of plant size, as it was found in capital productivity models.

High degree of conversion has a positive effect on two-factor total productivity though this result is inconclusive in the Mechanical Wood Industry. Comparison with the models using only two of the three independent variables showed that product quality and plant size are more related to total productivity in pulp and paper production, while in the mechanical wood industries the capital-output ratio has a stronger role in the model. In Paper Mills the specialization variable q_2 was used instead of q_1 and therefore different results were obtained.

When the same model was tested for the three-factor productivity measure Y_4, the results were more consistent (Table 12). The parameter estimate of plant size was significant in all branches. Its low values (.10 . . . .11) were reached in the mechanical wood industries and its high levels (.21 . . . .25) in pulp and paper production, suggesting that the earlier conclusions on plant size and total productivity are valid also for the three-factor measure. The elasticities are in the same range as for the two-factor indicators.

Capital-labour ratio obtains consistently negative parameter estimates but, apparently because materials input is included in the productivity measure, these estimates are no more significant except in two branches (Sawmills, Pulp and Paper Industry). The coefficient of output quality (q_1) is positive but it is significant only in two branches (Mechanical Wood Industry and Pulp and Paper Industry), both of which include pooled observations.

Additional tests were carried out to improve the goodness of fit of the total productivity models, but no general conclusions were made thereof.

Table 11. Two-factor Total Productivity Model

Branch	b_1	b_2	b_3	$\bar{R}^2$	F
Sawmills	.1541 (.0350)	−.4435 (.0535)	.7790 (.1561)	.7718	48.35***
Mechanical Wood Industry	.1805 (.0452)	−.3902 (.0681)	.3729 (.1960)	.4681	18.60***
Pulp Mills	.1195 (.1363)	−.3246 (.2821)	.2995 (.2525)	. .[1]	.96
Paper Mills[2]	−.0308 (.1120)	.1243 (.3104)	−1.4896 (.3917)	.6749	12.42**
Pulp and Paper Industry	.2625 (.0940)	−.5391 (.2059)	.6392 (.2068)	.3592	8.01**
Forest Industry	.1805 (.0457)	−.2799 (.0591)	.4425 (.1390)	.3478	18.60***

Function: $\ln Y_2 = b_1 \ln C + b_2 \ln K/L_2 + b_3 \ln q_1$

[1] Not reported as R^2 was so low that $\bar{R}^2$ became negative

[2] q_1 replaced by q_2

Table 12. Three-factor Total Productivity Model

Branch	b_1	b_2	b_3	$\bar{R}^2$	F
Sawmills	.1144 (.0216)	−.1331 (.0331)	.1264 (.0965)	.4954	14.74***
Mechanical Wood Industry	.0995 (.0337)	−.0763 (.0508)	.3239 (.1463)	.2005	6.02**
Pulp Mills	.2091 (.0660)	−.1124 (.1366)	.0507 (.1222)	.4747	6.87**
Paper Mills	.2371 (.0604)	−.1867 (.1293)	.2749 (.2485)	.5829	8.68**
Pulp and Paper Industry	.2508 (.0389)	−.1797 (.0852)	.3082 (.0856)	.6798	27.54***
Forest Industry	.1461 (.0274)	−.0152 (.0355)	.1402 (.0835)	.4086	23.80***

Function: $\ln Y_4 = b_1 \ln C + b_2 \ln K/L_2 + b_3 \ln q_1$

6. COMPARISON OF CROSS-SECTION AND TIME-SERIES MODELS

61. Scope and Limitations

In this chapter an attempt is made to compare the estimation results of the cross-section models to those of the time-series models estimated for the Finnish forest industries (1954—1974) by Simula (1979). Because of the somewhat different branch classification these comparisons are only possible for four industries, viz. Sawmills, Pulp Mills, Paper Mills, and Pulp and Paper Industry.

The two studies relied on the same source of data, but there are some differences in variable measurement, and these may influence the interpretation of comparisons. The measurement decisions in both cases were based on estimation trials which gave different conclusions in the two samples. The cross-section capital input covered the whole fixed capital stock and it was adjusted to capacity utilization, while the time-series measure was limited to machinery and equipment and no adjustments were made. In the cross-section measurement of labour input (employee hours), joint maintenance and other service departments in the integrated production units were taken into account, while in the time-series data this was not possible. It had to be assumed here that the measurement error caused by joint departments remained constant over time in relative terms. Finally, the output measures were different as in this study the calculations were based on net output and in the earlier study physical measures were used. The time-series data were collected at branch level, while the cross-section observations were obtained from individual plants. Pooled estimation was therefore not meaningful. In spite of the somewhat different interpretation of time-series and cross-section estimations their comparison could be of interest.

Table 13. Elasticity of Scale in Time- Series and Cross-Section CD Models

Branch	Elasticity of Scale[1]		$\bar{R}^2$	
	Time-Series	Cross-Section	Time-Series	Cross-Section
Two-factor CD Model				
Sawmills	1.3192	1.1431	.5797	.9684
Pulp Mills	1.6511	1.0017	.7997	.8094
Paper Mills	2.1521	.8968	.9770	.4699
Pulp and Paper Industry	2.4286	.9596	.9340	.5929
Three-factor CD Model				
Sawmills	1.1702	.9621	.8769	.9873
Pulp Mills	1.1865	.7616	.9900	.9321
Paper Mills	1.6254	1.0629	.9934	.8560
Pulp and Paper Industry	1.3690	1.5341	.9857	.8240

[1] $\sum b_i$ in functions:
$\ln Q = a + b_1 \ln L + b_2 \ln K$, and
$\ln Q = a + b_1 \ln L + b_2 \ln K + b_3 \ln M$

62. Production Functions

The time-series estimates of elasticity of scale are in general higher than those derived from the cross-section models (Table 13). The differences are particularly important in the pulp and paper branches and less pronounced in sawmills. The physical output-based two-factor model produced increasing rate of returns for all the four branches in the time-series data, while the net output-based cross-section data produced either decreasing or constant returns in pulp and paper production. If the estimation of bias in the latter models are taken into account (Chapter 514.) the differences are reduced, particularly in Sawmills and Pulp Mills, and increasing rate of returns is obtained for all branches except Paper Mills.

When the estimation was carried out for models with three factors of production, the time-series estimates for elasticity of scale were substantially reduced. The same effect was observed in the cross-section models for Sawmills and Pulp Mills, while in Paper

Mills and Pulp and Paper Industry the effect was opposite. The cross-section results were again lower than the time-series estimates except in Pulp and Paper Industry. This time Sawmills and Pulp Mills obtained decreasing returns. The incorporation of materials input in the CD models changes the interpretation of elasticity of scale estimates. Unfortunatly it is not possible to make definite conclusions on their magnitude since the effect of bias is not known.

In general, the time-series models have a better goodness of fit except for Sawmills and in the two-factor model for Pulp Mills. The largest differences are observed in the two-factor models of Paper Mills and Pulp and Paper Industry. The adjusted multiple correlation coefficients of the cross-section models are not, however, very robust vis-à-vis the formulation of the model which can be seen if the results are compared to the values in Table 4. The time-series estimations were not sensitive in this respect.

It is difficult to conclude what the rate of returns in the Finnish forest industries is in terms of "average" conditions, because the time-series results refer to an industry average over a certain period and the cross-section estimations to an industry average at a certain point of time as reflected in the existing capital stock. The time-series estimates above include those plants which were shut down during the period 1954 to 1973 and therefore did not exist in the 1974 capital stock. The estimation results indicate that different estimates for the rate of returns can be obtained depending on how the variables have been measured, particularly those of input. The time-series results may be realistic in engineering terms, i.e. there may be strongly increasing returns in the pulp and paper production when output is measured in tonnes. This technical relationship may not hold in pulp and paper production if the production function is measured in terms of net output instead of physical volumes. Finally, it should be noted that the time-series estimates represent short run and the cross-section results long run. Sawmilling appears to have increasing rate of returns in the two-factor environment but the evidence on pulp and paper production, regardless of the method of measurement, is not conclusive.

When the relevance of the CD function was tested by the Kmenta approximation, the parameter estimate b_3 of the square term in formula (2.6) was not significantly different from zero in the cross-section models perhaps indicating that the CD form could be accepted. In the time-series estimations it obtained a significant value in Paper Mills and Pulp and Paper Industry. The standard deviations of the capital-labour ratio in the cross-section data in these two branches are smaller than in the other industries and perhaps insufficient to yield proper estimates for b_3. The evidence on the relevance of the CD function remains therefore inconclusive.

The Kmenta function can also be used for obtaining information on capital's income share. Table 14 reports parameter estimates for b_1 in formula (2.6) together with the calculated average share of capital (the share of value added minus labour costs in value added). The time-series results refer here to twenty-one-year average and the cross-section results are for the branch average in 1974, when the capacities of forest industries were nearly fully utilized except in sawmilling. In general, the Kmenta approximations and the calculated average do not appear to produce similar estimates but they reflect differences in capital intensities between branches except the time-series Kmenta parameters. The cross-section Kmenta estimates could perhaps be considered the most plausible set of capital elasticity. The age structure of the capital stock may partly explain why the capital elasticity in Paper Mills

Table 14. Time-Series and Cross-Section Estimates of Capital's Income Share

Branch	Kmenta[1]		Average calculated	
	Time-Series	Cross-Section	Time-[2] Series	Cross-[3] Section
Sawmills	.6264	.1998	.3343	.6599
Pulp Mills	.7384	.3561	.5313	.7314
Paper Mills	.2979	.4158	.5200	.8985
Pulp and Paper Industry	.4450	.5079	. .	.8414

1) b_1 in function: $\ln Y_L = a + b_1 \ln(K/L) + b_2 \ln L + b_3 [\ln(K/L)]^2$

2) $\frac{Q_V - wL}{Q_V}$

3) Table 4

Table 15. Cross-Section and Time-Series Estimates of Elasticity of Substitution[1]

Branch	Elasticity of Substitution		$\bar{R}^2$	
	Time-Series	Cross-Section	Time-Series	Cross-Section
Sawmills	1.0071	1.8543	.8438	.5526
Pulp Mills	1.6642	2.2682	.8911	.2403
Paper Mills	1.2826	2.6326	.9303	.0490
Pulp and Paper Industry	1.3323	2.8581	.8942	.2397

1) Estimated from the ACMS relation

is higher than in Pulp Mills, even if in new mills this relationship is generally reversed.

The cross-section models produced substantially higher estimates for elasticity of substitution (σ) than those derived from time-series models (Table 15). If $\sigma > 1$, production factors technically resemble each other, and if $\sigma < 1$, there are limited possibilities to substitute one for another. The result is plausible if time-series estimates are interpreted as short-run relationships and the cross-section results reflect the long-term situation. With the exception of Sawmills the goodness of fit was poor in the cross-section models even though the parameter estimates are significant in all branches but Paper Mills. The very high cross-section estimates for σ in the pulp and paper branches cannot, however, be accepted because in these industries technology is more rigid than in mechanical wood processing and in particular sawmilling. Therefore, for the Finnish forest industries it appears that the ACMS relation referring to average production function does not yield plausible estimates of elasticity of substitution with time-series nor cross-section data.

The ACMS relationship was also estimated with the capacity variable to test the constancy of elasticity of substitution (Table 16). The goodness of fit improved and the elasticity estimates reduced in all cases. In the time-series models all the parameter estimates were significant, while the cross-section models failed in this respect (except b_2 in Pulp and Paper Industry). The evidence on the constancy of substitution elasticity in an average production function remains, therefore, inconclusive, even though there are strong reasons to believe that it is variable over a longer period of time and over the observed size classes. Because there is an upward trend in labour productivity and in wage rates in the time-series observations, the ACMS model produces good statistical results. As the variation of wage rates by plants is limited by nation-wide collective bargaining, only a small part of labour productivity can be explained by the expanded ACMS model in the cross-section data. Only in Sawmills were wage rate and plant size highly correlated, while in the pulp and paper branches the results are not seriously subject to multicollinearity.

63. Productivity Models

The time-series productivity models were estimated only for total productivity. The comparison of the estimation results is not,

Table 16. Times-Series and Cross-Section VES Production Function[1]

Branch	Times-Series		Cross-Section		$\bar{R}^2$	
	b_1	b_2	b_1	b_2	Time-Series	Cross-Section
Sawmills	.6016	.1114	.8335	.1401	.8873	.5857
Pulp Mills	.8531	.1823	1.5376	.1808	.9578	.3317
Paper Mills	.7412	.1259	.5112	.2855	.9837	.2336
Pulp and Paper Industry	.6703	.1557	1.7596	.1944	.9660	.3347

1) $\ln Y_L = a + b_1 \ln w + b_2 \ln C$

however, meaningful because their interpretation would be quite different. Total productivity over time can be taken as an estimate of time-related technical change while variation in cross-section productivity reflects differences in unit input consumptions by plants. If data had been available on the vintage of individual units, some meaningful comparisons could have been tried.

From the time-series models it was concluded that the output volume was the most important underlying factor for explaining changes in total productivity, which emphasizes the short-term nature of the dependent variable. Some improvement in the model's properties was gained in a few branches when average plant size and the variable describing business cycles were added. Models were estimated as first-order differences, which eliminated the high correlation between output volume and plant size. This study confirmed and expanded the earlier evidence on the role of plant size as the underlying factor in total productivity. Furthermore, capital-output ratio and output quality were found, in general, to be significant in explaining productivity variation. These two variables did not, in general, obtain significant parameter estimates in the time-series models.

7. DISCUSSION

71. Productivity Indices

The development strategy of the Finnish forest industries emphasizes intensive rather than extensive growth. As the removals correspond approximately to the production potential of the country's forests, this strategy is likely to become more pronounced in the future. It is unlikely that many new important mill sites will be established. The main emphasis will remain in the development and reconstruction of those existing production units which have the prospects for survival in the long run. In this situation there is a need for indicators which measure how efficiently the real available resources have been utilized at branch, company, plant or more detailed levels of measurement. This measurement should be sufficiently comprehensive to permit conclusions to be drawn on productivity change and variation with regard to individual production factors and total factor input.

One of the central problems of this study was to find suitable measures for productivity. When physical output and input data are available traditional volume-based productivity indicators can be calculated, if quality can be ignored. These kinds of partial indicators may relate to such inputs as labour, wood raw material, chemicals, energy, etc. if necessary conversion factors are known. Because of the heterogeneity of production factors meaningful aggregation is, however, difficult. The problem is further aggravated in the aggregation of total input. Furthermore, the measurement of capital input and other factors for which physical volume data are not available (e.g. maintenance materials, external services, and various fixed inputs), requires other approaches.

The aggregation schedule proposed in Chapter 22. appears to have a number of important statistical properties which would allow it to be considered superior to many alternative indices suggested in the literature. An appropriate weighting scheme remains to be selected. In a time series, periodically changing weights may describe the underlying technological relationships, thus adequately relieving the often uneasy assumption of constant returns to scale. In a cross-section, changing weights by pairs of observation, as used in this study, can be justified because they allow flexibility in technology between successive observations. Alternative schemes can, however, be applied if necessary information on production relationships is available to justify them.

In spite of its ambiguous definition, total productivity is a complex indicator which may be difficult to interprete. In time series it can be considered a measure of technical change but in cross section it refers to productivity differences by plants. The treatment of quality effects the interpretation of productivity change, i.e. total productivity may or may not include changes in output and input quality. For practical purposes, e.g. in measurement at plant or firm level, it is suggested that quality be included. This would allow, for instance, an increase in the degree of conversion with unchanged inputs reflecting in an increase in productivity. Quality is interpreted here as the mix of heterogeneous inputs and outputs. It has proved difficult to find more suitable weights for output and input components than those derived from unit prices, which assumes quality is reflected in price. Unit input coefficients are, however, recommended for weights in partial productivity indicators.

The suggested formulation of the productivity index is convenient as it does not necessarily incorportate neoclassical assumptions. The underlying production function was derived from the translog production function. The chosen flexible formulation can be considered a reasonable way to aggregate outputs and inputs. In fact, this is the main purpose of the underlying production function. If it can be shown that the production relationships can be formulated corresponding to e.g. the CD or CES conditions then another aggregating scheme is preferable. As we are usually dealing with average production functions in this kind of measurement, stricter functional formulations than those used in Chapter 22. are not likely to be clearly justified in spite of possible empirical evidence. This is because of the ambiguities related to the interpretation of the production function itself.

The chosen total productivity index appears theoretically justified and suitable for research purposes but, in practical applications at firm and plant level, the extensive calculations may not be possible. If the number of components in the index series is limited, only small if not neglible improvements in accuracy may be gained compared to simple schemes, such as Laspeyres, Paasche or Edgeworth. The more disaggregated data available on outputs and inputs, the more important is the choice of index formula.

In this study total productivity could have been measured using average unit prices as weights over the whole cross-section sample. Earlier studies on the Finnish forest industries have, however, shown that there are large variations in unit prices by plants, creating problems in the interpretation of results (Suomen . . . 1979). The use of average price weights would naturally mean a less ambitious index scheme thereby reducing the theoretical value of the results. On the other hand, the decision on ordering of observations in a cross section would be avoided, a problem which has apparently disturbed the interpretation of the results in this study.

The cross-section data used in the study were arranged according to mill size. The measurement results indicated that the very largest units do not necessarily yield the highest productivity, which may suggest diseconomies of scale after a certain plant size in the existing mills. In sawmilling, the size-related growth trend of total productivity cannot be identified and this may be due to the "bias" by integration and the degree of further conversion. In the pulp industry the plants divided into two groups according to main process. Each group contained size-related growth in total productivity. In paper mills plant size appears to be also related to total productivity, except in the very largest mills. The cross-section observations include the effects of both technological development, the nature of which (neutrality) can vary, and age (vintage). An analysis of productivity differences should aim at the identification of these effects before analysing other perhaps less fundamental factors, such as input and output quality.

In productivity analysis the main attention has traditionally been paid to labour productivity but in capital and materials intensive branches, such as forest industries, the use of capital and materials together with energy and other inputs should also be analysed. During the last few decades the importance of physical work in labour input has drastically reduced in forest industries. The role of labour in the production process has changed; work intensity is still important in many operations but much more vital is how man regulates the utilization of raw materials, machinery and equipment, etc. Partial labour productivity indicators therefore often yield very limited information on the rationale of labour input use in the production process.

There are several alternative methods for measuring partial and total productivity, depending on the selected output and input variables which should be chosen according to the intended use of information. The validity of the productivity indicators studied was evaluated by comparing them to a profitability indicator. As could be anticipated total productivity appeared to describe quite another aspect of the industry's efficiency than did profitability. There are, however, several alternative measures of profitability and therefore definite conclusions are difficult to make.

The measurement of capital and other inputs on which volume data are not available can be made by deflating value data. The reliability of input measurement depends, of course, on what extent the price index chosen describes the price change of the respective input. Capital input can be measured in terms of capital flow or stock. Both of them require information on the development of purchase prices of the capital goods since the date of acquisition. Furthermore, the calculation of capital flow and net capital stock needs information or assumptions on service lives, depreciation and retirement functions. In spite of somewhat more complex calculations capital flow measures should be preferred in total productivity calculations as they allow the direct calculation of the contribution of capital input to output.

Production factors are variable, semi-fixed or fixed in the short run. If actual output levels are used in measurement, productivity change of semi-fixed and fixed inputs tends to be large in branches with extensive cyclical fluctuations, such as forest industries. It is therefore suggested that productivity of these inputs be measured using both actual and capacity output and the results analysed to determine the effect of capacity utilization ratio on productivity. If quality is included in measurement, utilization correction can be made to the factor input to arrive at the capacity-based productivity indicator. The choice of productivity indicator is always a compromise where sacrifices and benefits need be evaluated carefully. The objectives of the desired information and the available data should be the principal criteria when making these decisions.

72. Production Models

The other central problem of this study was to find out factors which would explain productivity variation by plants in the Finnish forest industries. Firstly, a series of production functions were estimated to establish the main characteristics of production relationships by branches, primarily in terms of rate of returns and elasticity of substitution. Secondly, models were built for explaining partial and total productivity, and thirdly and finally, the cross-section results were compared to earlier time-series studies.

Like in many other productivity studies the weakest aspect of the present study possibly lies in the deficiences of data. Because of reasons of confidentiality, observations on individual plants were not available and the grouping of original data into three-plant averages was necessary. Furthermore, there were reasons to assume that the source data contained serious measurement errors, particularly with regard to physical volume -based indicators. Another problem related to data is the impact of integration on measurement. Integrated production units are frequent in pulp and paper production and also common in the mechanical wood industries. The data of the study failed largely to measure the degree of horizontal and vertical integration as it was only possible to obtain data on dummy variables. Integrated production units apply transfer pricing and therefore certain outputs, which are intermediate products or by-products for some industries and materials inputs for some others, were not necessarily valued at market prices. This problem could have been eliminated, had observations been available on integrated units as a whole. The data collected and compiled in the Industrial Statistics of the Central Statistical Office in Finland are not very applicable for the analysis of production relationships in the forest industries. In particular, the present treatment of integrated production units and joint departments creates insurmountable problems.

The main characteristics of production relationships were evaluated on the basis of average production functions. The interpretation of such functions is vague as they describe production technology in some sort of average conditions in the existing industry. Information on average production functions have limited value for planning purposes because blueprint and average technology are not necessarily correlated. Nevertheless, average production functions are easy to calculate and as they often behave well they have been extensively used in empirical applications of production theory. They were also used in this study but an attempt was made to interprete the estimation results with appropriate reservations. A number of factors create non-optimum decision-making in the Finnish forest industries and there was no prior guarantee that frontier production functions would have resulted in meaningful estimations with the available data.

The estimated production functions were derived using traditional theory in order to enable the identification of parameter estimates. At the same time the scope of hypotheses was narrowed, which may have affected the CES function in particular. On the other hand, additional hypotheses would possibly have been difficult to verify because of the data limitations. The CD function was used primarily to test the rate of returns and the CES functions to obtain information on the nature of elasticity of substitution. More general forms are also available. They may yield better fit than restricted functions, as used in this study, but their results are more difficult and ambiguous to interprete. The CD and

CES formulations were deemed sufficient to test the nature of the selected key aspects of production.

Traditional production theory appears to describe reasonably well the production relationships in the Finnish forest industries, depending on how the output and input variables have been measured. The underlying neoclassical hypotheses cannot, however, be assumed valid with the possible exception of sawmilling, which adds to the limitations of the model interpretation. Furthermore, it is implied that the imperfections of the markets influence estimations equally in individual branches.

The level of aggregation and thereby the homogeneity of production technologies appear to be related to the applicability of the neoclassical production function. The higher the level of aggregation, the more justified assumptions may be made on the nature of markets or production technology. The interpretation of results becomes difficult since e.g. economies of scale at aggregate level may conceal diseconomies of scale at process level. Decision-making based on information on production characteristics in such branches as "forest industry", "mechanical wood industry", or even "pulp and paper industry" may therefore be seriously limited.

The estimation results of the CD functions would suggest partly increasing and higher rate of returns in the mechanical wood industries than in pulp and paper production. High capital intensity in the latter may not be fully compensated by returns from the reduced use of other inputs, notably labour. The heterogeneity of observations in individual branches may, however, blur these results. Small mills often tend to specialize and large mills concentrate in production of bulk products. In homogeneous conditions, with regard to product range and process, increasing rate of returns could possibly have been observed more universally. In general, alternative formulations of the CD function give a relatively good fit. The CD model performs better in the mechanical wood industries than in pulp and paper production which may be taken as an indication of the existence of a more general production function in the latter. The estimation results were relatively insensitive to capacity utilization adjustment. However, the adjustment should be made whenever possible.

The fit of the CES model was again better in the mechanical wood industries than in pulp and paper production. As labour productivity is the dependent variable in the two models, it may be that meaningful results cannot be obtained if the industry is very capital intensive or the level of labour productivity depends heavily on other factors than the capital-labour ratio or wage rate. Furthermore, wage rate may not have sufficient variation within individual branches to reflect in productivity differences. The CES results would, in general, imply that the elasticity of substitution is not necessarily constant in the Finnish forest industries if measured in terms of average production function. Its higher values in pulp and paper production do not, however, confirm more rigid technology, with regard to factor proportions, than in the mechanical wood industries. Production functions were estimated in a form where labour productivity was the dependent variable. In capital intensive industries this is not necessarily the best way to analyse the overall production relationships. The estimation of the translog production function revealed that the assumption of non-homotheticity cannot be rejected. This was further confirmed by the inclusion of dummy variables in the basic production functions. Possible sources of non-homotheticity are process and product range, plant size, and integration. Had the estimations been possible within plant categories according to these characteristics, more information could have been obtained on the rate of returns by branches. Because of the limited number of observations this was not possible. It is apparent that at least the pulp and paper industries are composed of so heterogeneous plants that the constant returns to scale assumption cannot be accepted for the industry as a whole, and a more disaggregated analysis need be carried out before conclusions can be made.

The comparison of the time-series and cross-section estimations was seriously limited by differences in variable measurement. It appeared that physical volume data on output tend to raise estimates of the rate of returns. Quite different conclusions on production characteristics can be made based on engineering and economic data. Both the cross-section and time-series analyses gave increasing returns in sawmilling but the results in the other branches remained inconclusive. The most plausible estimates of capital share were obtained through the cross-section Kmenta function which was not, however, able to confirm the relevance of the CD function. The comparison of the time-series and cross-section models also confirmed that the ACMS relation is not a reasonable way to obtain information on elasticity of substitution, at least in capital intensive branches.

The estimation results of production functions suffer from simultaneity and measurement bias which is possibly of such magnitude that the conclusions made may be influenced. It is possible that the rate of returns is seriously underestimated. The measurement error in capital input also appears to be important. The same may hold true with regard to labour input measurement because of the treatment of joint maintenance and other departments, but this bias was not estimated. It can be concluded that the data used and the approach applied in estimating production functions yielded results which have to be interpreted with great care.

73. Productivity Models

The main objective of production functions in productivity analysis is to show how the aggregation of inputs should be made. As the neoclassical assumptions are not valid in the Finnish forest industries the weights derived from income shares are more justified than those based on input elasticities. The hypothesis on constant returns to scale was rejected, but constant elasticity of substitution was accepted because otherwise the aggregation would have been difficult to operationalize. These assumptions were applied for all the branches studied although individual industries would possibly have deserved a special treatment. A universal method, however, enabled the direct comparability of estimation results by branches.

Productivity variation was explained by the substitutable input ratio, input and output quality, input price ratio, process characteristics, and capacity utilization. The dependent variables were productivity ratios and many of the explanatory variables were also expressed as ratios. The general interpretation of ratio variables is obscure and the model's endogenous and exogenous relationships are easily blurred. For instance, net output per employee-hour is not necassarily a measure of efficiency but it can be considered as a proxy for factor proportions. There is no reason to assume that high values of this kind of ratio imply efficient production. It is not surprising to find the ratio correlated with other measures of the capital-labour ratio or its proxies. Another problem is to what extent the chosen variables can be considered genuine decision variables. In spite of these problems there is a reason to expand the scope of traditional production function analysis where only output level or labour productivity emerge as independent variables.

Productivity differentials were best explained by models where capital-labour ratio and plant size were independent variables. With the exception of the K/L ratio in the materials productivity models, this result was obtained for all the partial and total productivity measures tried. The ranges of productivity elasticities were somewhat wider with regard to K/L ratio than plant size. An increase in capital-labour ratio improves labour productivity but decreases both capital and total productivity. In the existing structure of the Finnish forest industries higher capital intensity has not apparently been fully compensated by the unit consumption of total input. On the other hand, it has to be recognised that capital intensity is not directly related to productivity, i.e. an increase in K/L ratio does not necessarily raise labour productivity. There is apparently an optimum capital intensity but it cannot be assumed equal for production units of different size or product range.

Plant size appears to have a positive impact on productivity with the exception of materials productivity. In general, small production units have better possibilities to utilize wood raw material more efficiently than large mills. The plant size elasticities vary in all the other productivity models in the same, relatively small range (.10 . . . 27) being lower than those of the K/L ratio. Capital intensity grows more rapidly than the size of production unit. It appears that the highest possible plant size within the existing units does not give maximum productivity measured in terms of capital input or total factor input. The partly conflicting role of plant size and capital-labour ratio would deserve additional study on their *ex ante* relationships. The optimum mill sizes have traditionally been evaluated based on unit investment costs per capacity output. The scope of such analyses should be broadened to duly cover all input factors and experience on the *ex ante* and *ex post* production relationships.

Apart from K/L ratio and plant size, output quality tends to be an important factor underlying capital, materials and total productivity. It was generally measured in terms of the degree of conversion (the share of value added in the gross value of production) which had a positive impact on productivity. The result may be interpreted as supporting evidence for the strategy of Finnish forest industries to increase their degree of further conversion. Among the other significant factors underlying productivity differentials, the mix and quality of labour input were identified.

The analysis of productivity differentials may have suffered most from the lack of data on horizontal integration which might have emerged as one of the key variables. The output quality measures incorporate some elements of vertical integration and therefore may also be interpreted as an indication of the possible inportance of integration. Another possible key variable is the age of the main machinery and equipment, for which meaningful data were not available. The pure vintage effect is, however, not necessarily decisive as certain process characteristics (e.g. machine width and speed in paper industry, the automation of process control) can be much more important.

Based on the experiments made with production functions the bias of productivity models is likely to be of such magnitude that the above conclusions have to be interpreted which great care, even though a certain uniformity in the results support them. It is possible that the elasticities of capital-labour ratio are on the low side for this reason.

The present study revealed how a certain set of typical variables used in the economic analysis of production and productivity, can yield only limited information on factors underlying productivity differentials in the Finnish forest industry. A deeper insight to the problem could be obtained, should engineering and management data be available. It is possible that the set of key variables underlying productivity is insufficient and should be increased. The results referred to the existing industry as an average, but this information has only limited value for planning new investment. Finally, the aggregation of heterogeneous processes proved to be risky until a level is reached where heterogeneity is again large enough to yield well-behaving information. Nevertheless, the kind of analysis applied in the study extends the scope of productivity analysis from labour productivity towards other inputs and total input.

The study dealt superficially with materials productivity. As an aggregate its analysis is not interesting because it incorporates the utilization of quite different components such as wood and other fibrous raw materials, chemicals, energy, etc. Each of them should be analysed separately in terms of productivity. To permit an analysis which could produce interesting information on substitution possibilities between these input components and other production factors, more detailed data would be necessary than was available in this study. Materials inputs have often been considered closely related to output levels. However, efficiency in their utilization depends on their substitutability, the rate of capacity utilization, etc. and each of these factors should be studied separately.

If total productivity is followed over time and it is used as a decision criterion, it would be possible to minimize the consumption of real resources per output unit which in the long run is a main factor influencing the international competitiveness of the industry. The effect of *ex ante* investment decisions has to be emphasized as plant size and, to a large extent, capital-labour ratio are determined at the planning stage. Of all the factors studied, these two are the main contributors to productivity differentials. On the other hand, substantial variations in productivity measures were due to other factors, which allow *ex post* improvement. In order to investigate how the industry's efficiency could be improved in this respect, additional information and other approaches than those used in this study would be necessary.

8. SUMMARY

The international competitiveness of the Finnish forest industries, which operate primarily for export markets, depends a.o. on the prices of production factors and their consumption per output unit. At least in the short run the industry is in a situation where it has to adapt to the market and price development of their products, while the possibilities to influence factor prices are limited. Productivity increase has therefore been seen as one of the key means by which the industry can itself improve its competitiveness. International comparisons have revealed that there are good possibilities to create such increases. Using this background as a basis, the study aimed at obtaining information on production relationships and productivity in the Finnish forest industries with a view to improving their international competitiveness both at branch and plant level. This requires the search for appropriate comprehensive productivity indicators and the analysis of factors underlying productivity variation which are the main objectives of this study. The study complements an earlier analysis on the same subject using times-series data.

The study data were based on information on individual plants in 1974, obtained from the files of Industrial Statistics in the Central Statistical Office in Finland. The observations can be assumed to contain measurement errors due to grouping of original plant data, integration, transport costs, etc. On such central aspects as process characteristics or product range, information was available only in the form of dummy variables. Like in many other productivity studies the weakest aspect of the present study lies possibly in the deficiences of data.

The properties of alternative production functions were reviewed first to obtain information on the characteristics of production relationships and on certain aspects of productivity. The theoretical properties on the average production functions used were critically discussed. The constant elasticity of substitution function served as the basis of the analysis, which centered on the rate of returns and the nature and size of the elasticity of substitution. Because of data limitations frontier production functions were not estimated. Furthermore, there are a number of factors in the Finnish forest industries which create non-optimum decision-making and these would essentially limit the possible value of information derived from these frontier functions.

Production theory was expanded to cover factors underlying productivity variation when measured with regard to labour, capital, materials, and total factor input. The relationships between profit and productivity maximisation lead to a general model where productivity variation was explained by the substitutable input ratio reflecting the chosen technology and transferring the impacts of several underlying factors on productivity. The conceptual model further included plant size, input and output quality, capacity utilization, and process characteristics as explanatory factors. The model was qualified for individual partial and total productivities.

A total productivity index was developed which does not necessarily incorporate neoclassical assumptions and allows a certain flexibility in the underlying technological relationships and few restrictions with regard to the rate of returns and elasticity of substitution. In spite of its unambiguous definition total productivity is a complex indicator which may be difficult to interprete. In time series it can be considered as a measure of technical change but in cross section it refers to productivity differences by plants. The measurement of total productivity is also sensitive to the number of inputs included in the total factor input, how outputs and inputs are measured, whether adjustment for capacity utilization has been made in fixed or semi-fixed inputs, and how the weighting scheme has been selected. The measurements were carried out in three branches (sawmilling, pulp and paper mills) showing that there may be certain diseconomies of scale in the very largest plants. Product mix should first be differentiated before measurement. The heterogeneity of the plants studied easily ef-

fects the measurement results, thus making anlysis difficult.

The information provided by various productivity indicators was verified with regard to a chosen profitability measure. The results showed that profitability and productivity described quite different aspects of plant efficiency. Capital productivity is alone a very powerful indicator incorporating a lot of variation both in total productivity and profitability.

The estimation of the CD and CES production functions showed that the results are sensitive to the method of measurement of output and input variables. The adjustment for capacity utilization appeared to have little effect on conclusions. Production theory appears to work better when value added-type measures, rather than physical volumes, are used for output. This is possibly due to the heterogeneity of process characteristics, product range, integration, etc. Engineering production functions may therefore yield quite different results from those derived from functions where value-added output measures are used.

Increasing rate of returns were identified in sawmilling while in the other branches of forest industries the cross-section evidence remained inconclusive. In general, the rate of returns would be higher in the mechanical wood industries than in pulp and paper production but the result is subject to branch heterogeneity in measurement.

The fit of the CD models was not good in all the alternative formulations and therefore their explanatory capacity is limited. Neither the estimation of the Kmenta function nor the ACMS relation yielded reasonable estimates for the elasticity of substitution. This may have been due to insufficient variation in capital and labour inputs to allow the estimation with necessary precision. It is, however, evident that growing capital intensity makes it increasingly difficult to substitute capital for labour. The results of the CES function supported the assumption that wage rate variation may be a significant factor in explaining labour productivity differentials in spite of the partly institutional nature of the labour markets. The results of the VES function suggested non-constancy of the elasticity of substitution but they remained inconclusive. Neither could the non-homotheticity assumption be rejected.

The study focussed on the analysis of entire branches. Had larger samples been available, estimation could have been carried out to test the homotheticity by groups of observations arranged according to process, integration and plant size. As this was not possible, only dummy variables were used. The results showed that in sawmilling significant sources of non-homotheticity were not identified. In pulp mills, process, plant size and possibly vintage, and in paper mills at least product range could be such important factors that the analysis of production relationships could benefit if it could be made within groups of plants rather than at branch level as in this study.

There are a number of possible reasons why the fit of the production functions estimated remained low. The error term may be due to different vintages, variation in factor prices and different expectations of future factor price ratios. The problem of simultaneity is also apparent in the analysis. Finally, there may be important measurement errors in the source data. The bias estimations suggested that the real rate of returns could be higher than those estimated. The OLS results may be blurred by the simultaneity bias to such an extent that conclusions have to be interpreted with great care. The same holds true with bias originating from measurement errors.

In productivity models capital-labour ratio and plant size emerged as the most important variables explaining variation in most cases. Output quality, if measured as the degree of conversion, was also an important determinant in all branches studied except paper mills where it had to be replaced by an output quality variable describing the degree of specialization. In general, capacity utilization ratio did not prove to be a significant variable and the few exceptions may be due to measurement errors.

In the mechanical wood industries a certain increase in labour productivity requires a somewhat larger relative increase in K/L ratio than in plant size. This relationship may be stronger in pulp and paper production than in the mechanical wood industries. In the latter branches high labour productivity is associated with high degree of conversion but the relationship is more difficult to analyse in pulp and paper production because of transfer pricing. Wage rate appears to foster labour productivity as well. Several organization levels or extensive staff functions do not necessarily improve the overall labour productivity. Proxies used for labour input quality were not very successful in explaining differentials and this may indicate that they did not perhaps illustrate the true quality aspect of labour input.

Large mills tend, in general, to yield high capital productivity, particularly in pulp and paper production. Also capital-labour ratio is intensively correlated with capital productivity. Output quality had a more marginal impact than labour productivity in the model. The relationship was positive in the mechanical wood industries but the evidence was inconclusive for pulp and paper production. In paper mills a high degree of specialization was closely related to high capital productivity. The quality of capital input was not a significant factor in the models, which may be due to the failure to measure it.

The materials productivity model included labour-materials ratio, plant size and output quality as explanatory variables. The interpretation of the ratio variable remained somewhat vague because the true substitution between the two inputs may be limited. In mechanical wood industries the larger plants obtained higher materials productivity. In the pulp and paper industry the evidence was inconclusive.

The impact of plant size on total productivity was very important. However, small mills using small amounts of capital per labour input have high total productivity and capital productivity, particularly in the mechanical wood industries. Capital-labour ratio was less significant in the three-factor productivity models than in the two-factor models. In general, the fit of the total productivity models was relatively good, which has to be appreciated since the dependent variable can be interpreted as a residual.

The scope of comparison between the time-series and cross-section estimations was limited because of differences in variable measurement. Quantitative analysis was only possible for production functions as the interpretation of the productivity models was quite different in the two cases. The short run estimates of the rate of returns derived from the earlier time-series models were generally higher than those produced by this study. The long-run cross-section estimates can be considered more plausible even though they are apparently biased. The Kmenta model suggested the CD function can be accepted on the basis of this study, while the time-series models would indicate that the elasticity of substitution does not necessarily equal one in pulp and paper industry. The results have to be considered, however, inconclusive. The direct estimates of σ were higher in the cross section than in the time series, which is plausible. It is not likely, however, to obtain higher values in pulp and paper production compared to in the mechanical wood industries. In general, the time-series models obtained a higher degree of determination because of the inherent growth trends in most of the variables. Quality, mix, and other related variables produced more interesting results for them. The impact of these variables may be more of a short run nature while the long run functions have to derive their explanatory capacity from more fundamental aspects of production relationships.

The study extended the scope of productivity analysis from labour productivity towards other inputs and total factor input. If total productivity is followed over time and used as a decision criterium, it would be possible to minimize the consumption of real resources per output unit which in the long run is a main factor influencing the industry's international competitiveness. Furthermore, labour productivity indicators give only limited information on the rationale of labour input use and should be used with care as decision variables.

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SELOSTE

TUOTTAVUUDEN VAIHTELU SUOMEN METSÄTEOLLISUUDESSA

Suomen metsäteollisuus toimii pääosin vientimarkkinoiden varassa. Alan kansainvälinen kilpailukyky riippuu mm. tuotannontekijöiden hinnoista ja niiden kulutuksesta tuoteyksikköä kohden. Ainakin lyhyellä aikavälillä teollisuus on tilanteessa, jossa sen on sopeuduttava tuotteittensa markkina- ja hintakehitykseen, kun taas mahdollisuudet vaikuttaa panosten hintoihin ovat rajoitetut. Tuottavuuden nousu on sen vuoksi nähty eräänä keskeisistä keinoista parantaa teollisuuden kilpailukykyä. Kansainväliset vertailut ovat osoittaneet, että Suomessa on hyvät mahdollisuudet kohottaa tuottavuuden tasoa. Tätä taustaa vasten tutkimuksessa pyrittiin hankkimaan tietoa tuotantosuhteista ja tuottavuudesta Suomen metsäteollisuudessa. Kansainvälisen kilpailukyvyn parantamispyrkimyksissä sekä toimialan että tuotantoyksikön tasolla tarvitaan sopivan laaja-alaisia mittareita tuottavuudelle. Samalla joudutaan analysoimaan tuottavuuden vaihteluun vaikuttavia tekijöitä. Näihin tavoitteisiin pyrkinyt tutkimus täydentää aikaisempaa aikasarja-aineistoon perustuvaa selvitystä samasta aihepiiristä.

Tutkimusaineiston pääosan muodosti Tilastokeskuksen teollisuustilaston keräämä informaatio yksittäisistä tuotantoyksiköistä v. 1974. Aineistoon voidaan olettaa sisältyvän mittausvirhettä, jonka syinä voivat olla alkuperäisten tehdaskohtaisten tietojen ryhmittäminen havainnoiksi, integraatio, kuljetuskustannukset jne. Sellaisista keskeisistä näkökohdista kuin prosessin erityispiirteet tai tuotevalikoima tietoa oli käytettävissä vain dummy-muuttujien muodossa. Kuten monissa muissa tuottavuustutkimuksissa tämänkin selvityksen heikoin kohta lienee tutkimusaineistoon liittyvissä puutteissa.

Aluksi arvioitiin vaihtoehtoisten tuotantofunktioiden ominaisuuksia informaation hankkimiseksi tuotantosuhteiden luonteesta ja eräistä tuottavuuteen liittyvistä näkökohdista. Keskimääräisen tuotantofunktion teoreettisia ominaisuuksia arvioitiin kriittisesti. Tuottojen asteeseen ja korvausjoustoon keskittyneen analyysin lähtökohtana oli tuotantofunktio, jossa korvausjousto oletettiin vakioksi. Käytettävissä olevien tietojen asettamien rajoitusten vuoksi ns. frontier-tuotantofunktiot jätettiin tarkastelun ulkopuolelle. Sitä paitsi Suomen metsäteollisuudessa vallitsee joukko tekijöitä, joiden vuoksi syntyy epäoptimaalista päätöksentekoa, mikä olennaisesti rajoittaisi frontier-funktioiden avulla hankittavan tiedon käyttöä.

Tuotantoteoriaa laajennettiin kattamaan tekijöitä, jotka vaikuttavat tuottavuuden vaihteluun, kun mittaus on suoritettu työn, pääoman, materiaalipanoksen ja kokonaispanoksen suhteen. Voiton ja tuottavuuden maksimoinnin välisiä suhteita käytettiin hyväksi muodostettaessa yleinen malli, jossa tuottavuuden vaihtelua selitettiin keskenään korvautuvien panosten välisellä suhteella. Suhde heijastaa valittua teknologiaa ja välittää useiden muiden tekijöiden vaikutuksen tuottavuuteen. Mallin muina selittävinä muuttujina olivat tehdaskoko, panosten ja tuotosten laatu, kapasiteetin käyttöaste sekä prosessin erityispiirteet. Malli määriteltiin niin yksittäisille osittaistuottavuuksille kuin kokonaistuottavuudellekin.

Kokonaistuottavuuden mittausta varten kehitettiin indeksi, joka ei välttämättä sisällä uusklassisen tuotantoteorian oletuksia sallien tietyn joustavuuden teknologisissa riippuvuussuhteissa ja sisältäen vähän tuottojen astetta ja korvausjoustoa koskevia rajoituksia. Huolimatta määritelmällisestä selkeydestään kokonaistuottavuus on monisäikeinen indikaattori, jota saattaa olla vaikea tulkita. Aikasarjassa se voidaan ymmärtää tekniseksi muutokseksi, mutta poikkileikkausaineistossa se viittaa tuotantoyksiköiden välisiin tuottavuuseroihin. Laadun käsittely mittauksessa sekä käytetyt painot vaikuttavat kokonaistuottavuusindeksin tulkintaan. Mittaus on myös herkkää sen suhteen, käytetäänkö arvoihin vai fyysisiin määriin perustuvia tietoja, montako panosta on mukana ja onko kapasiteetin käyttöaste otettu huomioon kiinteiden ja puolikiinteiden panosten mittauksessa. Kolmella toimialalla (sahat sekä massa- ja paperitehtaat) suoritetut mittaukset osoittivat, että kaikkein suurimmat tuotantoyksiköt saattavat kärsiä skaalahaitoista. Tehtaat olisi ennen mittausta ryhmiteltävä tuotevalikoiman perusteella homogeenisiin ryhmiin, sillä muuten tulosten analysointi on vaikeaa.

Kokonaistuottavuusindikaattoreiden informaatiota verrattiin valittuun kannattavuusmittariin. Tulokset osoittivat, että kysymyksessä on kaksi erilaista tehokkuuden näkökohtaa. Toisaalta pääoman tuottavuus on yksin erittäin voimakas indikaattori, joka sisältää runsaasti niin kokonaistuottavuuden kuin kannattavuudenkin vaihtelua.

CD- ja CES-tuotantofunktioiden estimointi osoitti, että tulokset ovat herkkiä tuotos- ja panosmuuttujien valinnalle. Kapasiteetin käyttöaste ei vaikuttanut tehtyihin päätelmiin. Perinteinen tuotantoteoria näyttää toimivan paremmin käytettäessä jalostusarvopohjaisia tuotosmuuttujia verrattuna fyysisiin suureisiin, mihin lienee

syynä prosessien tai tuotevalikoiman heterogeenisuus, integraatio jne. Insinöörituotantofunktiot saattavat sen vuoksi tuottaa aivan erilaisia tuloksia tavanomaisiin jalostusarvopohjaisiin tuotantofunktioihin verrattuna.

Sahateollisuudessa tuottojen aste oli kohoava, kun muilla metsäteollisuuden aloilla tulosten perusteella ei voida tehdä päätelmiä. Yleisesti tuottojen aste näyttää olevan korkeampi mekaanisessa puuteollisuudessa kuin massan ja paperin tuotannossa, mutta toimialojen heterogeenisuus saattaa selittää eron.

CD-mallien vaihtoehtoiset formuloinnit eivät antaneet yhdenmukaisesti hyviä tuloksia, joten niiden selityskyky jäi rajoitetuksi. Kmenta-funktio ja ACMS-suhde eivät tuottaneet kohtuullisia korvausjoustoestimaatteja. Tämä saattoi aiheutua riittämättömästä vaihtelusta pääoma- ja työpanoksessa välttämättömän tarkkuuden saavuttamiseksi estimoinnissa. On kuitenkin ilmeistä, että kohoava pääomavaltaisuus vaikeuttaa työn korvaamista pääomalla. CES-funktion tulokset tukivat puolestaan oletusta, että palkka on merkittävä työn tuottavuuseroja selittävä tekijä huolimatta työmarkkinoiden osittain institutionaalisesta luonteesta. VES-funktion estimointitulokset viittaavat siihen, ettei työn ja pääoman korvausjousto olisi vakio. Epähomoteettisuusoletusta ei voitu tulosten perusteella hylätä. Tutkimuksen kohteena olivat kokonaiset toimialat. Jos käytettävissä olisi ollut suurempia näytteitä, estimointi olisi voitu suorittaa ryhmittäin käyttäen kriteereinä prosessien ominaisuuksia, integraatioastetta ja tehdaskokoa. Homoteettisuuden testaamiseksi edelleen käytettiin sen vuoksi dummy-muuttujia. Tulosten perusteella massatehtaissa prosessi, tehdaskoko ja mahdollisesti pääkoneiden ikä ja paperitehtaissa ainakin tuotevalikoima saattavat olla niin tärkeitä tekijöitä, että niiden vaikutus olisi eliminoitava ennen tuotantosuhteiden analyysia.

Tuotantofunktioiden verraten alhaiseen selityskykyyn on useita mahdollisia syitä. Virhetermi on saattanut aiheutua tuotantokoneiston iästä, tuotannontekijäin hinnoista ja niitä koskevista odotuksista, jotka jäivät tarkastelun ulkopuolelle. Myös simultaanisuusongelma on analyysissa ilmeinen. Lisäksi havaintoaineistoon sisältynee huomattavaa mittausvirhettä. Harhan estimoinnit osoittivat, että todellinen tuottojen aste lienee estimoituja korkeampi. Simultaanisuus ja mittausvirheet saattavat vaikuttaa pienimmän neliösumman menetelmällä saatuihin tuloksiin niin paljon, että päätelmiä on tehtävä varoen. Erityisesti massa- ja paperiteollisuudessa CD- ja CES-funktioilla saadut heikot tulokset selittynevät mittausvirheillä.

Tuottavuusmalleissa pääoma-työpanossuhde ja tehdaskoko osoittautuivat tärkeimmiksi muuttujiksi, jotka selittivät kaikkien tutkittujen osittais- ja kokonaistuottavuusindikaattoreiden vaihtelua tuotantoyksiköittäin. Jalostusasteella mitattu tuotoksen laatu oli myös tärkeä tekijä lukuunottamatta paperitehtaita, joissa puolestaan erikoistumisaste antoi hyviä tuloksia. Sen sijaan kapasiteetin käyttöaste ei saanut yleensä merkitseviä parametriestimaatteja, mihin lienee osaltaan olleet syynä mittausvirheet.

Tietty työn tuottavuuden lisäys vaatii suhteellisesti jonkin verran suuremman lisäyksen pääoma-työpanossuhteessa kuin tehdaskoossa mekaanisessa puuteollisuudessa. Massa- ja paperiteollisuudessa vuorovaikutus lienee voimakkaampi. Korkea työn tuottavuus liittyy korkeaan jalostusasteeseen mekaanisessa metsäteollisuudessa, mutta siirtohinnoittelun vuoksi tilannetta on vaikea analysoida massa- ja paperiteollisuudessa. Palkkataso näyttää vaikuttavan positiivisesti työn tuottavuuteen. Useat organisaatiotasot tai laajat esikuntaosastot eivät näytä välttämättä parantavan työn tuottavuutta kokonaisuuden kannalta. Työpanoksen laatua kuvaavat muuttujat eivät saaneet malleissa juuri merkitseviä parametriestimaatteja, mikä lienee osoitus muuttujien heikosta kyvystä kuvata työpanoksen todellista laatua.

Suurissa tuotantoyksiköissä päästään yleensä korkeaan pääoman tuottavuuteen, erityisesti massa- ja paperiteollisuudessa. Pääoma-työpanossuhde näyttää myös olevan positiivisesti korreloitunut pääoman tuottavuuden vaihtelun kanssa. Tuotoksen laadun merkitys oli malleissa selvästi vähäisempi kuin työn tuottavuutta analysoitaessa. Korkea jalostusaste parantaa pääoman tuottavuutta mekaanisessa puuteollisuudessa, mutta massan ja paperin tuotannossa riippuvuutta ei voitu selvästi osoittaa. Sen sijaan paperin ja kartongin valmistuksessa korkea erikoistumisaste on läheisesti yhteydessä korkeaan pääoman tuottavuuteen. Pääomapanoksen laadun mittauksessa tuskin onnistuttiin, koska muuttuja ei saanut merkitsevää parametriestimaattia tutkituissa malleissa.

Materiaalituottavuutta selittävinä muuttujina olivat työ-materiaalipanossuhde, tehdaskoko ja tuotoksen laatu. Suhdemuuttujan tulkinta jäi jossain määrin epämääräiseksi, koska panosten korvautuminen lienee käytännössä rajoitettua. Mekaanisessa puuteollisuudessa suurten tuotantoyksiköiden materiaalituottavuus näyttää muodostuvan korkeammaksi kuin pienissä laitoksissa. Massa- ja paperiteollisuudessa päätelmiä ei voitu tulosten perusteella tehdä.

Tehdaskoon vaikutus kokonaistuottavuuteen osoittautui varsin tärkeäksi, joskin pienet tehtaat, jotka käyttävät vähän pääomaa työpanosta kohden, saavuttavat myös verraten korkean kokonaistuottavuuden. Sama ilmiö todettiin myös pääoman tuottavuutta analysoitaessa erityisesti mekaanisessa puuteollisuudessa. Mallien selitysastetta voitiin pitää varsin korkeana, koska selitettävä muuttuja voidaan tulkita jäännöstermiksi.

Aikasarja- ja poikkileikkausmallien vertailu jäi niukaksi muuttujien erilaisen mittauksen vuoksi. Kvantitatiivinen tarkastelu oli mahdollista vain tuotantofunktioiden osalta, koska tuottavuusmallien tulkinta oli erilainen. Aikasarjamalleista johdetut lyhyen aikavälin estimaatit tuottojen asteelle olivat yleensä korkeammat kuin poikkileikkausmallien pitkää aikaväliä kuvaavat tulokset. Jälkimmäisiä voitanee pitää hyväksyttävämpinä hypoteesien kannalta huolimatta niihin sisältyvästä harhasta. Kmenta-mallin perusteella CD-funktio voitaisiin hyväksyä poikkileikkausaineistoa käytettäessä, kun taas aikasarjamallien perusteella korvausjousto ei välttämättä ole yksi massa- ja paperiteollisuudessa. Jouston suorat poikkileikkausestimaatit olivat korkeammat kuin aikasarjamalleissa, mikä on hypoteesien mukaista. Sen sijaan massa- ja paperiteollisuudessa saatuja mekaanista puuteollisuutta korkeampia estimaatteja ei voitane pitää hyväksyttävinä. Aikasarjamallien selitysaste oli yleensä poikkileikkausanalyysin tuloksia korkeampi useimpiin muuttujiin sisältyvän samansuuntaisen trendin vuoksi. Tuotoksen ja panosten laatua, rakennetta ja niihin liittyviä ominaisuuksia kuvaavat muuttujat tuottivat aikasarjamalleissa mielenkiintoisempia tuloksia kuin poikkileikkausanalyysissa. Näiden muuttujien vaikutus lienee tyypillinen lyhyellä aikavälillä, kun taas pitkän aikavälin mallien on selityksessään nojauduttava tuotantosuhteiden perustavampaa laatua oleviin piirteisiin. Tuottavuuden vaihtelua selittävät aikasarja- ja poikkileikkausmallit osoittivat tuotannon tason keskeiseksi kokonaistuottavuutta selittäväksi tekijäksi.

Tutkimus laajensi tuottavuusanalyysia työn tuottavuudesta muiden panostekijöiden ja kokonaispanoksen suhteen mitattujen tunnusten suuntaan. Jos kokonaistuottavuutta seurataan jatkuvasti ja sitä käytetään päätöksentekokriteerinä, olisi mahdollista minimoida resurssien käyttö tuotosyksikköä kohden, mikä pitkällä aikavälillä ratkaisevasti säätelee teollisuudenalan kansainvälistä kilpailukykyä. Lisäksi on huomattava, että työn tuottavuusmittarit antavat vain rajoitettua informaatiota työpanoksen käytön järkiperäisyydestä kokonaisuutena ja niitä pitäisi sen vuoksi käyttää varoen päätösmuuttujina. Tutkimuksen tulokset osoittavat, että investointien suunnittelun merkitys on ratkaiseva tuottavuuden muodostumiselle, koska silloin pitkälti määritellään niin tehdaskoko kuin pääoma-työpanossuhdekin, jotka erottuivat tuottavuuden selittäjinä tärkeimmiksi tutkituista muuttujista.

Appendix 1. Data by Branches

Sawmills

No. of observation	Q_G	Q_N	Q_F	C	L	L_H	L_S	L_T	L_W	W	K	K_q	M	D_{11}	D_{21}	D_{22}	D_{23}	D_{24}	D_{31}
1	1329.6	615.1	4814.4	4.4	14.4	24174.4	.199	.012	.854	243.5	511	.543	715.3	0	1	0	0	0	1
2	1427.5	506.8	5283.9	3.7	16.7	27493.6	.120	.028	.907	287.7	464	.430	920.9	0	1	0	0	0	0
3	2940.0	1062.4	9292.5	8.7	31.5	50516.2	.095	.017	.835	512.2	574	.595	1877.5	0	1	0	0	0	1
4	3067.5	880.7	10242.0	7.8	28.3	48325.8	.118	.040	.958	520.3	948	.714	2186.8	1	1	0	0	0	0
5	2933.6	1076.8	10497.7	8.1	24.2	42615.5	.122	.027	.880	442.9	658	.516	1777.2	0	1	0	0	0	0
6	5757.2	2315.3	21905.1	13.5	47.5	85915.5	.111	.054	.786	934.4	1646	.566	3469.3	0	1	0	0	0	0
7	5565.0	2236.8	22110.1	13.2	45.5	75016.1	.162	.058	.801	910.3	1458	.664	3331.2	0	1	0	0	0	1
8	9053.5	3007.2	33173.4	20.2	65.0	117702.0	.111	.056	.802	1335.8	2597	.506	6045.9	0	0	1	0	0	0
9	15445.7	6172.1	42949.0	33.3	76.7	145538.7	.113	.078	.995	1868.7	14475	.544	9273.6	0	0	1	0	0	1
10	17125.0	7385.9	45788.0	36.2	108.5	192586.7	.106	.085	.777	2457.5	6968	.793	9903.4	0	0	1	0	0	0
11	12593.3	3978.1	46695.7	31.7	82.3	146408.0	.093	.040	.748	1751.3	1972	.551	8615.1	0	0	1	0	0	0
12	14032.1	5095.6	47803.4	32.2	80.9	146962.0	.097	.056	.707	1699.7	4639	.596	8937.1	0	0	1	0	0	0
13	14452.7	4638.0	48182.7	43.7	118.5	260036.5	.089	.060	.844	2791.5	6435	.462	9814.9	1	0	1	0	0	0
14	15897.8	6181.4	53832.9	34.4	107.2	205214.7	.121	.072	.692	2531.7	4460	.480	9716.7	0	0	1	0	0	1
15	16044.7	5702.1	53970.0	44.2	93.5	176627.8	.116	.060	.740	2456.0	10578	.518	10342.4	0	0	1	0	0	0
16	24506.3	6361.5	63411.0	83.3	146.0	247476.0	.080	.052	.917	3546.3	12444	.659	18144.5	0	0	0	1	0	0
17	22084.0	7546.7	68994.0	60.0	121.0	216761.0	.074	.056	.890	3972.7	7627	.577	14564.4	0	0	0	1	0	0
18	24256.5	7821.6	76541.0	57.5	177.2	319766.5	.128	.052	.770	4125.7	17630	.547	16433.8	0	0	0	1	0	0
19	30432.0	10755.4	94239.3	60.0	201.7	381013.7	.116	.060	.846	4756.3	14910	.674	19677.3	0	0	0	1	0	1
20	30282.0	12562.0	97731.7	85.0	189.3	350500.7	.127	.063	.599	5509.7	15130	.518	17721.0	0	0	0	1	0	1
21	27606.7	10282.6	97980.3	65.0	153.3	286113.3	.076	.038	.892	3828.0	9470	.586	17323.2	0	0	0	1	0	0
22	31061.7	11959.6	99454.7	81.7	149.3	270456.3	.096	.047	.838	3435.7	8925	.698	19124.7	0	0	0	1	0	0
23	37829.0	16291.6	135804.0	156.7	196.7	363429.0	.163	.085	.843	5627.0	15077	.576	22841.1	0	0	0	0	1	1
24	65932.0	44497.2	167674.7	168.3	459.7	816459.0	.104	.063	.657	12475.0	47370	.619	25344.3	0	0	0	0	1	1
25	50078.0	22764.8	169150.0	93.3	286.7	516858.7	.112	.060	.627	6904.0	34829	.597	27357.6	0	0	0	1	0	1
26	59900.3	24559.1	190531.3	66.7	369.7	618150.7	.082	.049	.711	8955.7	50122	.589	35347.2	0	0	0	1	0	0
27	88333.7	34893.6	243833.3	166.7	379.0	660296.7	.109	.056	.742	9330.0	55102	.616	53441.9	0	0	0	0	1	0
28	66953.7	21656.4	255132.7	146.7	294.7	532352.7	.090	.051	.970	7960.3	42105	.688	45294.2	0	0	0	0	1	0
29	112778.7	41379.7	429186.7	210.0	348.0	636814.7	.101	.069	.816	9089.0	52049	.701	71400.0	1	0	0	0	1	0

Appendix 1. Continued

Mechanical Wood Industry[1)]

No. of observation	Q_G	Q_N	Q_F	C	L	L_H	L_S	L_T	L_W	W	K	K_q	M
1	15824.0	11838.7	28811.0	46.7	120.0	228201.0	.233	.156	.763	4309.0	30116	.750	7334.8
2	21006.3	15891.3	61484.7	60.0	141.0	252007.0	.144	.110	.717	3585.0	13760	.691	3571.0
3	24174.0	17556.9	66961.0	76.7	115.3	215407.7	.150	.150	.717	2996.7	35156	.798	11378.7
4	43361.3	33760.6	124259.3	146.7	233.3	426294.7	.170	.112	.737	6000.7	40585	.753	19885.5
5	6517.0	5128.7	2789.0	5.3	106.3	174496.7	.097	.052	.747	1825.0	5786	.557	2372.8
6	10761.7	7623.6	7672.7	9.0	163.7	300900.0	.112	.073	.805	3774.3	20187	.621	5499.2
7	12995.7	7957.3	9359.3	15.0	247.7	397332.3	.153	.084	.798	5082.7	15895	.557	6683.7
8	12195.7	8765.7	9411.3	16.7	183.3	326201.0	.145	.100	.830	4011.7	14358	.201	5477.1
9	21319.3	13999.2	15473.0	13.3	311.7	515271.3	.079	.063	.889	6794.0	27269	.720	9851.7
10	22823.0	15889.8	16312.3	25.0	313.3	497923.0	.187	.090	.821	6432.0	27320	.633	12835.7
11	24981.7	17116.0	18790.7	27.0	393.3	681911.0	.141	.085	.789	8616.3	38867	.617	13597.5
12	64563.0	41813.3	47655.0	50.0	807.5	1298158.0	.115	.066	1.000	14843.0	72398	.682	31868.3

[1)] Excluding Sawmills. Observations 1 to 4 are particle board plants and 5 to 12 plywood mills

Pulp Mills

No. of obsevation	Q_G	Q_N	Q_F	C	L	L_H	L_S	L_T	L_W	W	K	K_q	M	D_{11}	D_{12}	D_{13}	D_{21}	D_{22}	D_{23}	D_{31}
1	6398.3	2608.7	12695.3	15.3	47.7	81166	.035	.007	.794	1047.0	13370.0	.683	3826.8	1	0	0	1	0	0	0
2	11413.7	4474.7	23388.0	23.3	74.3	135257	.054	.057	1.000	2281.3	7747.0	.571	6939.5	1	0	0	1	0	0	0
3	15673.3	5724.8	28583.3	33.3	41.7	71736	.008	.008	.945	1209.0	5587.3	.815	10043.5	1	0	0	1	0	0	0
4	32427.0	17893.5	32238.7	41.7	219.7	385267	.127	.123	.770	6327.7	67435.3	.838	16933.4	0	1	0	1	0	0	0
5	41031.0	28957.9	36941.0	40.0	267.7	482530	.115	.107	.691	7994.3	50760.7	.738	15366.1	0	1	0	1	0	0	0
6	33196.3	15969.9	38596.3	40.0	162.3	349700	.177	.167	1.000	5442.0	48684.0	.856	18895.4	0	1	0	1	0	0	0
7	66658.7	30683.3	57685.7	65.0	320.7	571765	.121	.102	.636	9763.7	100095.2	.823	39622.0	0	1	0	0	1	0	0
8	68136.5	35299.4	62856.0	71.5	408.5	736181	.179	.126	.482	12224.5	114171.0	.588	38238.2	0	1	0	0	1	0	1
9	36195.7	10194.3	72507.7	63.3	98.7	172105	.095	.101	.984	3110.7	17616.0	.760	26003.0	1	0	0	0	1	0	0
10	83239.0	43403.3	90594.7	120.0	198.7	349539	.126	.136	1.000	6385.3	71631.7	.790	41852.6	0	0	1	0	0	1	0
11	100063.2	58818.0	101042.4	110.0	409.4	756081	.211	.169	.566	12346.4	201387.0	.809	52223.0	0	0	1	0	0	1	1
12	121385.0	46381.3	146533.3	191.7	521.3	934477	.199	.146	.472	15845.0	168934.3	.881	85807.1	0	0	1	0	0	1	0
13	164119.5	85064.3	158923.5	189.2	730.0	1282445	.207	.143	.588	19438.0	312448.2	.762	92005.4	0	0	1	0	0	1	1
14	131430.3	73660.9	166699.0	180.0	645.3	1158512	.199	.135	.593	19886.7	213319.7	.854	64269.4	0	0	1	0	0	1	0

Appendix 1. Continued

Paper Mills

No. of observation	Q_G	Q_N	Q_F	C	L	L_H	L_S	L_T	L_W	W	K	K_q	M	M_v	D_{11}	D_{12}	D_{13}	D_{21}	D_{22}	D_{23}	D_{31}
1	84585.3	84542.5	30497.3	36.3	572.3	1017788	.164	.105	.710	16893.7	123779.7	.767	42842.5	42842.5	0	0	1	1	0	0	0
2	60414.0	60390.9	36838.3	49.3	428.3	756161	.163	.092	.733	11717.3	94543.0	.837	23132.5	23132.5	0	0	1	1	0	0	1
3	63354.7	63322.2	41948.3	38.7	178.7	316591	.215	.119	.933	5162.0	67396.7	.826	32501.0	32501.0	0	1	0	1	0	0	0
4	177059.2	176983.4	59633.0	51.2	787.0	1336784	.249	.121	.641	21292.5	133699.7	.705	75834.5	75834.5	0	0	1	0	1	0	0
5	90275.2	90226.7	65293.0	80.7	228.0	406307	.191	.138	.702	7132.7	101362.0	.615	48559.1	48559.1	1	0	0	0	1	0	1
6	135142.0	135065.9	83679.7	103.3	579.7	1128878	.136	.072	.764	21576.0	223265.0	.861	76125.5	76125.5	0	0	1	0	0	1	0
7	120279.2	120218.3	88099.0	94.0	462.8	822594	.223	.103	.824	14760.2	149610.6	.782	60873.3	60873.3	0	0	1	0	1	0	1
8	326629.7	326459.4	108390.3	260.0	520.7	941513	.170	.129	.654	16393.3	210777.3	.845	170272.0	170272.0	0	1	0	0	0	1	0
9	191041.0	190937.4	138986.0	150.7	659.7	1152599	.181	.106	.450	19107.7	144274.3	.878	103582.4	103582.4	0	1	0	0	0	1	0
10	192032.0	191919.5	189408.7	269.0	611.0	1104003	.279	.176	.576	18862.7	258216.3	.838	112453.9	112453.9	1	0	0	0	0	1	1
11	275076.0	274923.3	282778.7	341.0	650.7	1137862	.138	.107	.667	20691.7	334773.3	.805	152667.2	152667.2	1	0	0	0	0	1	1
12	309673.7	309505.0	315912.3	344.7	991.3	1839073	.201	.128	.638	31980.3	479382.7	.842	168648.3	168648.3	1	0	0	0	0	1	1

APPENDIX 1. Explanations

Units of Measurement

Variable	Name	Unit of measurement
Q_G	Gross value of output	1000 FIM
Q_N	Net value of output	1000 FIM
Q_F	Physical output of the main products produced	m^3 or ton
C	Capacity	1000 m^3 or ton
L	Number of employees	number
L_H	Number of employee hours	hour
L_S	Share of salaried personnel in the total number of employees	share
L_T	Share of technical staff in the number of workers	share
L_W	Share of the hours of production workers in the total hours of all workers	share
W	Salaries, wages and fringe benefits	1000 FIM
K	Total replacement value of buildings, machinery and related items	1000 FIM
K_q	Share of machinery and equipment in K	share
M	Value of raw materials and supplies	1000 FIM

Dummy variables

Sawmills

D_{11} – 0 frame saw only
1 other (circular, band, etc.)
D_{21} – 0 capacity more than 20 000 m^3/yr
1 capacity 20 000 m^3/yr or less
D_{22} – 1 capacity 20 001–50 000 m^3/yr
0 other
D_{23} – 1 capacity 50 001–100 000 m^3/yr
0 other
D_{24} – 1 capacity more than 100 000 m^3/yr
0 other
D_{31} – 1 further conversion
0 no further conversion

Mechanical Wood Industry

D_{11} – 1 sawmills
0 wood-based panel mill

Pulp

D_{11} – 1 mechanical or semi-chemical pulp
0 chemical pulp
D_{12} – 1 sulfite pulp
0 other
D_{13} – 1 sulfate pulp
0 other
D_{21} – 1 capacity 50 000 t/yr or less
0 capacity more than 50 000 t/yr
D_{22} – 1 capacity 50 001–150 000 t/yr
0 other
D_{23} – 1 capacity more than 150 000 t/yr
0 other
D_{31} – 1 market pulp mill
0 integrated with paper production

Paper

D_{11} – 1 wood-containing printing and writing paper
0 other
D_{12} – 1 wood-free printings and writings, folding box-board, tissue, specialities
0 other
D_{13} – 1 kraft pulp-based paper and board (unbleached and bleached)
0 other
D_{21} – 1 capacity 50 000 t/yr or less
0 capacity more than 50 000 t/yr
D_{22} – 1 capacity 50 001–150 000 t/yr
0 other
D_{23} – 1 capacity more than 150 000 t/yr
0 other
D_{31} – 1 integrated with mechanical pulp production
0 integrated with chemical pulp production; includes one observation with no integration

Pulp and Paper

D_{11} – 1 pulp mill
0 paper mill

APPENDIX 2. Correlation Matrix of Main Explanatory Variables Used in Production and Productivity Models

	L_H	K_U	w	C	K/L_1	L/M_2	q_1	
Sawmills								
K_U	.820							
w	.762	.550						
C	.882	.668	.793					
K/L_1	.735	.781	.693	.691				
K/L_2	.702	.943	.537	.555	.880			
L/M_2	.060	–.195	–.072	–.134	–.279	–.316		
q_1	.297	.113	.074	.126	–.043	–.014	.742	
q_2	–.286	–.041	–.088	–.136	–.094	.023	–.537	–.454
Mechanical Wood Industry								
K_U	.713							
w	.343	.406						
C	.510	.624	.617					
K/L_1	.333	.501	.654	.442				
K/L_2	.400	.865	.508	.558	.739			
L/M_2	.175	–.145	.056	–.314	.061	–.242		
q_1	.300	.044	–.031	–.075	–.118	–.174	.574	
q_2	–.326	–.010	–.186	.159	–.120	.110	–.495	–.484
Pulp mills								
K_U	.955							
w	.032	–.039						
C	.874	.857	.219					
K/L_1	.673	.782	–.132	.671				
K/L_2	.674	.806	–.111	.632	.963			
L/M_2	.067	–.055	–.234	–.296	–.171	–.165		
q_1	.272	.265	–.242	.001	.340	.345	.769	
q_2	–.067	.010	–.164	.019	.015	.001	–.415	–.395

	L_H	K_U	w	C	K/L_1	K/L_2	L/M_2	q_1
Paper Mills								
K_U	.815							
w	.147	.368						
C	.578	.745	.409					
K/L_1	.072	.533	.618	.763				
K/L_2	.059	.602	.430	.455	.777			
L/M_2	.005	–.240	–.436	–.573	–.680	–.511		
q_1	–.113	–.364	.400	.221	–.679	–.528	.688	
q_2	–.015	.288	.226	–.120	.104	.563	.074	–.342
Pulp and Paper Industry								
K_U	.887							
w	.204	.234						
C	.711	.801	.360					
K/L_1	.466	.677	.235	.728				
K/L_2	.419	.703	.169	.535	.875			
L/M_2	–.042	–.198	–.337	–.473	–.440	–.362		
q_1	.308	.125	–.202	–.110	.035	.044	.585	
q_2	.027	.221	.069	–.040	.095	.361	–.122	–.259
Forest Industry								
K_U	.872							
w	.536	.572						
C	.704	.773	.550					
K/L_1	.633	.778	.771	.650				
K/L_2	.609	.802	.707	.614	.901			
L/M_2	–.079	–.257	–.224	–.384	–.290	–.372		
q_1	.096	–.099	–.278	–.192	–.248	–.245	.565	
q_2	–.195	–.027	–.245	–.102	–.207	–.021	–.126	–.195

ODC 791+792+796 ISBN 951-651-055-8

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ISBN 951-651-055-8

Arvi A. Karisto Oy:n kirjapaino
Hämeenlinna 1983