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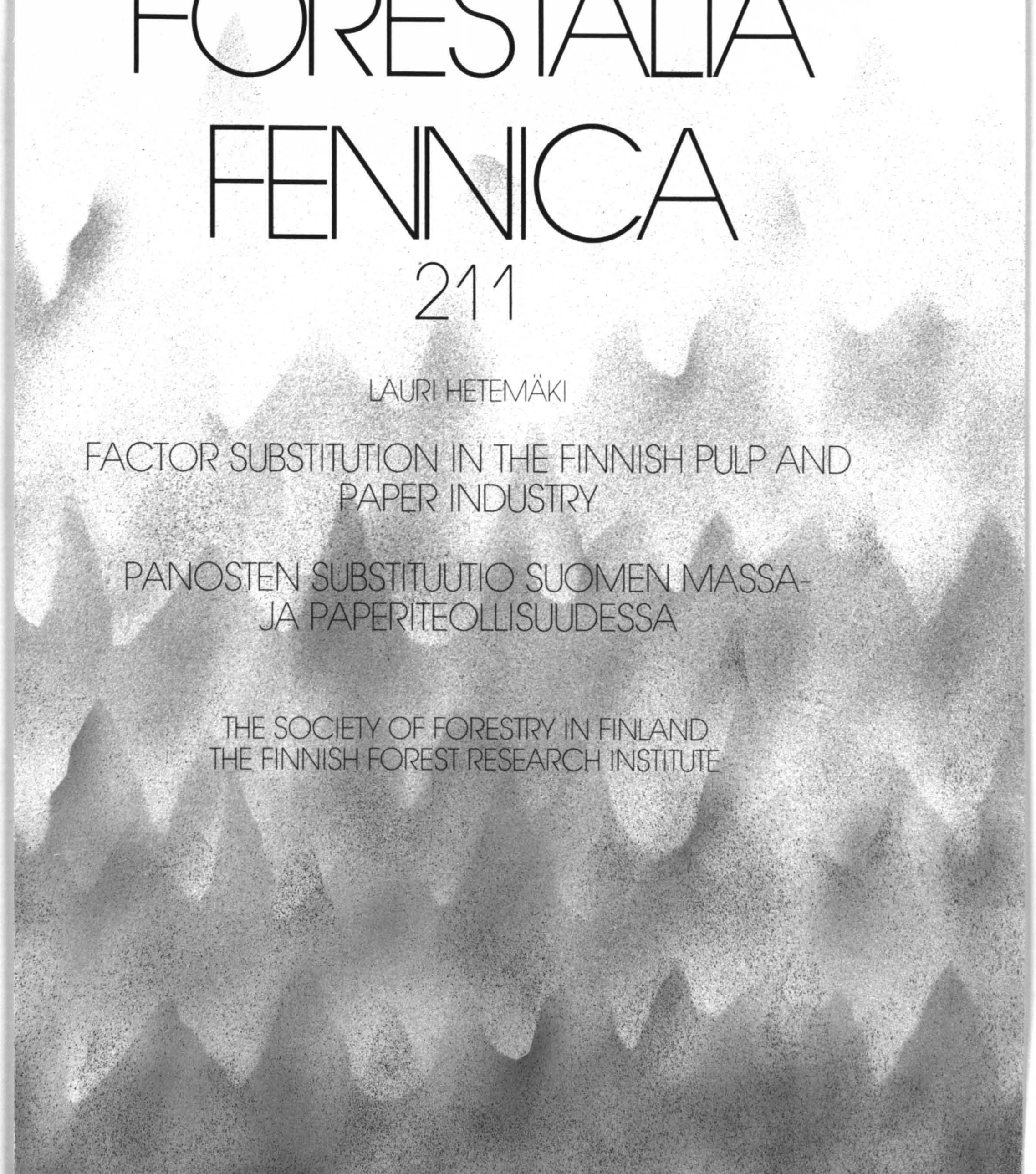

LAURI HETEMÄKI

FACTOR SUBSTITUTION IN THE FINNISH PULP AND PAPER INDUSTRY

PANOSTEN SUBSTITUUTIO SUOMEN MASSA- JA PAPERITEOLLISUUDESSA

THE SOCIETY OF FORESTRY IN FINLAND
THE FINNISH FOREST RESEARCH INSTITUTE

ACTA FORESTALIA FENNICA

Acta Forestalia Fennica was established in 1913 by the Society of Forestry in Finland. It was published by the Society alone until 1989, when it was merged with Communicationes Instituti Forestalis Fenniae, started in 1919 by the Finnish Forest Research Institute. In the merger, the Society and the Forest Research Institute became copublishers of Acta Forestalia Fennica.

Prior to the merger, 204 volumes had appeared in Acta Forestalia Fennica, and 145 volumes in Communicationes (numbers 1–99, 101–146).

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ACTA FORESTALIA FENNICA 211

FACTOR SUBSTITUTION IN THE FINNISH PULP AND PAPER INDUSTRY

Panosten substituutio Suomen massa- ja paperiteollisuudessa

Lauri Hetemäki

Approved on 12.1.1990

The Society of Forestry in Finland — The Finnish Forest Research Institute

Helsinki 1990

Hetemäki, L. 1990. Factor substitution in the Finnish pulp and paper industry. Seloste: Panosten substituutio Suomen massa- ja paperiteollisuudessa. Acta Forestalia Fennica 211. 87 p.

The study examines the factor demands of the Finnish pulp and paper industry. In the theoretical part ot the study, factor demand equations are derived using neoclassical production theory. In the empirical part, econometric factor demand model is estimated using annual time-series data for the period 1960—1986. The relationships of factor demands and their prices are examined in terms of own price, cross price and substitution elasticities.

It is assumed that the "representative firm" in the pulp and paper industry is minimizing its costs of production at a given output level. In addition, a number of other assumptions are made which enable the production technology to be represented by a cost function, in which the inputs are capital, labour, energy and raw materials. From the cost function, the factor demand equations, i.e., the cost share equations, are derived by applying Shephard's lemma. The equations are transformed to estimable form using translog approximation for the underlying factor share functions.

The study differs from the previous factor demand studies by applying the error correction model based on the Granger Representation Theorem and the results of the cointegration literature to model the dynamics of the factor demand. This approach provides a statistically consistent method for estimating the long-run static factor demand equations and the corresponding short-run equations. In general, the econometrics of integrated processes (e.g., stationarity and cointegration tests) applied in the present study have not been applied before in factor demand systems models.

The empirical results of the study indicate that the error correction approach can be applied to estimations of the factor demands for the pulp and paper industry. In both industry sectors, the adjustment to short run disequilibrium (price shocks) appears to be fairly rapid. The most significant results of the calculated elasticities are that the factor demands of the pulp and paper industries clearly react to changes in factor prices and that there are significant substitution possibilities between the different inputs. The absolute values of the elasticities are, on average, somewhat larger than have been obtained in previous studies.

Tutkimuksessa tarkastellaan Suomen massa- ja paperiteollisuuden tuotantopanosten kysyntää. Tutkimuksen teoreettisessa osassa johdetaan neoklassisen tuotantoteorian mukaiset panosten kysyntäyhtälöt. Tutkimuksen empiirisessä osassa estimoidaan ekonometriset panoskysyntämallit Suomen massa- ja paperiteollisuudelle käyttäen vuosittaista aikasarja-aneistoa ajanjaksolta 1960—1986. Panosten kysyntöjä tarkastellaan oman hinnan, risti- ja substituutiojoustojen perusteella.

Tutkimuksen lähtökohtana on oletus, että sekä massa- että paperiteollisuudessa "edustavan yrityksen" tavoitteena on tuotteen valmistaminen mahdollisimman pienillä tuotantokustannuksilla. Tuotantoteknologiaa kuvataan kustannusfunktiolla, jossa tuotantopanoksina ovat pääoma, työ, energia ja raaka-aineet. Kustannusfunktion derivaattaominaisuuden perusteella saadaan johdettua panosten kysyntäyhtälöt (kustannusosuusyhtälöt) ratkaisematta yrityksen optimointiongelmaa. Malli saadaan estimoitavaan muotoon kuvaamalla tuotantoteknologiaa joustavamuotoisella translogfunktiolla.

Tutkimus eroaa keskeisesti aikaisemmista joustavamuotoisista panoskysyntämalleista soveltamalla Grangerin esityslauseeseen perustuvaa virheenkorjausmallia lyhyen aikavälin dynaamisen panoskysynnän mallittamiseen. Lähestymistapa mahdollistaa staattisen pitkän aikavälin ja dynaamisen lyhyen aikavälin yhtälöiden tilastollisesti konsistentin estimoinnin. Tutkimuksessa käytettyä integroituneiden prosessien ekonometriaa (esim. stationaarisuus- ja yhteisintegraatiotestejä) ei ole yleensäkään aikaisemmin sovellettu panoskysyntäsysteemien mallittamisessa.

Tutkimuksen empiiriset tulokset osoittavat, että käytetty virheenkorjausmalli soveltuu massa- ja paperiteollisuuden panosten kysyntöjen mittaamiseen. Lisäksi tulokset osoittavat, että molemmilla toimialoilla sopeutuminen lyhyen aikavälin epätasapainoilmiöihin (hintamuutoksiin) on melko nopeaa. Laskettujen joustoestimaattien merkittävimpinä tuloksina voidaan pitää sitä, että massa- ja paperiteollisuuden tuotantopanoksien kysynnät reagoivat selvästi hintamuutoksiin ja että niiden välillä on merkittävää korvautuvuutta (substituutiota). Joustojen absoluuttiset arvot ovat keskimäärin hieman suurempia kuin aikaisemmissa tutkimuksissa saadut.

Keywords: pulp and paper industry, factor demand, cost function, time series, cointegration.
ODC 861+796.

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ISBN 951-40-1093-0
ISSN 0001-5636

Mäntän kirjapaino Oy, 1990

Contents

Preface

This report is part of a larger project, "The Structure and Mechanisms of the Roundwood Markets in Finland" ("Puumarkkinoiden rakenne ja toimintamekanismit Suomessa"), which was jointly financed by the Finnish Forest Research Institute and the Academy of Finland. The project was conducted at the Section of Business Economics of the Finnish Forest Research Institute under the leadership of Pekka Ollonqvist. Pekka Ollonqvist initially suggested to me that I carry out the analysis on factor demands in the Finnish pulp and paper industry. Throughout the project, he has not only been a source of new ideas, but has also provided concrete comments and suggestions for improving the report. I am most grateful to him for this and the friendly encouragement he has extended to me during the project.

I would like to thank Pekka Ilmakunnas and Erkki Koskela for their guidance, suggestions and constructive criticism, which have helped to improve the report. Martti Hetemäki, Jari Kuuluvainen and Matti Viren read the manuscript and provided comments and valuable suggestions concerning different parts of the report. Thanks are due to Jouko Hämäläinen and Matti Palo, my former and present superiors at the Department of Forest Economics, for providing excellent research facilities. Malcolm Waters checked the language and Ville Ovaskainen helped to sharpen the presentation in Finnish summary. Heikki Pajuoja taught me how to use Xerox Ventura. To them, the members of the Supervision Committee of the project and many other colleagues and friends who have been involved in and contributed to this study I wish to express my sincere gratitude. Financial support from the Yrjö Jahnsson Foundation is gratefully acknowledged.

I would like to express my gratitude to my parents, Leila Hetemäki and the late Päiviö Hetemäki, for the support and encouragement they have given to me in my studies. Finally, I am indebted to Eeva who has endured the stresses of the research period.

Helsinki, January 1990

Lauri Hetemäki

1. Introduction

11. Background and purpose of the study

The pulp and paper industry has, together with the sawmill industry, formed the basis of the Finnish economy for over a hundred years or so. Although its share of gross national product has steadily declined during the last decades, it still plays an important role in the Finnish economy. The value added share of the forest industry (pulp and paper industry) was around 18 (13) per cent of total manufacturing in 1985 and its share in exports around 38 (30) per cent. The positive effect of the forest industry on the balance of payments is reinforced by the fact that the industry requires very little in the way of imported inputs. Indeed, domestic raw materials constitute over 90 % of the total raw materials inputs in the pulp and paper industry (and the forest industry in general). The manufacture of wood and paper products, printing and publishing employed around 155 000 persons in 1985/86. In addition, the forest industry channels around 10 000 million Fmk annually to the national economy in the form of stumpage and forestry income. Furthermore, the forest industry's, and in particularly the pulp and paper industry's, total effect on the Finnish economy is greater than can be deduced from these crude figures. For example, the linkage effects that the industry has had on the building of paper machines and the material and engineering industries in general as well as on exports of know-how have been significant (see Haltia & Simula (1988)).

A part from the direct and indirect economic effects mentioned above, the pulp and paper industry is of central importance for the planning of national energy and forest resource policies. For example, the industry's interests in and influence on decisions concerning the possible building of a new nuclear reactor for securing energy supply or on the decisions concerning the utilization of the country's forest for production purposes, as opposed to establishing National Parks where cuttings are not allowed, are obvious. On the other hand, the pulp and paper industry has to cope with, and try to influence, government energy and forest policies as expressed in pricing policy, taxation structure and incentives.

Considering the importance of the forest industry in Finland, research applying modern economic theory and econometrics to study the industry's production technology and employment of production factors has been surprisingly sparse. In particular, there are few studies which explicitly analyse the factor input substitution possibilities and technological development of the forest industry. To know to what extent there is scope for factor substitution is essential not only for the industry, which may have only limited power to influence its input and output prices, but also for energy and forest resources policy-planners, who must know the potential effects of and possibilities for energy and forest resource conservation measures.

Most of the Finnish pulp and paper industry's production is sold on the world market, where the industry's market power in relatively small, and the industry can therefore be assumed to operate on a output market where conditions are close to perfect competition. The assumption of competitive input markets is more controversial, but as will be argued later (Section 41.) it appears to be a better approximation of reality at the aggregate level than the imperfect competition case. Consequently, if the assumption of perfect competition in input and output markets holds and if exogeneous input factor prices increase, the industry is unable to pass without losing competitiveness and market shares in the world pulp and paper markets. In that case, the industry is either forced to close down or to adjust its production technology to take account of the changes in relative factor prices. Even if the output market is imperfect, so that the industry is able to influence its output price, potential substitution possibilities to exist.

Thus, the key question for the pulp and

paper industry is: How flexible is the production structure in the face of changing costs (or availability) of factor inputs, i.e., capital, labour, materials and energy? More precisely, to what extent can the production technology in the industry react to relative factor price changes and how can the possible responses be explained in terms of the factor' own-price sensitiveness and substitution possibilities among inputs? For example, consider a national stumpage price agreement, which affects the price of roundwood and thus the costs of producing pulp and paper. The effects of the agreement on the level of the demand for roundwood can be examined by devering the own-price elasticity measure for roundwood input. However, because the demand for roundwood is interrelated with the demand for other inputs, the stumpage price agreement may have also an effect on the demand for capital, labour and energy inputs. This is a result of the fact that firms typically choose their input mix in a way that minimizes the total cost of producing a given level of output. Thus, cheaper factors are substituted for dearer ones. Consequently, if, for example, the opportunities for substitution between roundwood and other factor inputs were limited, then it might be expected that the adjustment to (permanently) higher stumpage costs would be difficult. The unit cost of production would rise, the composition of output would, in the long run, shift away from roundwood-intensive products and the technological structure would probably change considerably. If, on the other hand, roundwood input was a strong substitute for other inputs, then one might expect that the industry could adjust smoothly to problems created by stumpage costs and roundwood shortages.

It is also important to know whether the factor inputs are substitutes or complements. For example, consider the effects of higher stumpage prices on energy demand in the pulp and paper industry. If roundwood and energy are substitutes, then, ceteris paribus, higher stumpage prices will increase the demand for energy. If roundwood and energy are complements, then higher stumpage prices will decrease the demand for both roundwood and energy. Further, if roundwood and energy are complements, then energy saving incentives and roundwood conservation measures are consistent policy goals. Energy saving incentives would decrease the demand for both energy and roundwood, as would roundwood conservation measures.

Besides questions concerning the price sensitiveness of factor demand, it is important for the industry to know what influence technical changes has had on the use and productivity of different inputs. The extent to which possible factor substitution has been induced by changes in relative factor prices as opposed to being the effect of autonomous, biased technical change is important for determining the effects of further factor price changes on factor demand.

The existing studies on the production structure of the Finnish pulp and paper industry, either do not analyse the above questions or they do it in a rather restrictive way. Some of the studies are restricted to value added models and no intermediate inputs are included in the analysis (Simula 1979). Studies which do include material inputs do not separately model roundwood input (Simula 1983, Törm & Loukola 1986). Furthermore, all existing studies are based on the assumption of static equilibrium or instantaneous adjustment. Finally, the underlying data generation process of the models is not been studied in detail in any of the studies.

The purpose of this study is to try to analyse the sensitiveness of factor demand in the Finnish pulp and paper industry to changes in relative factor prices and technical change in a less restricted and more detailed and robust way than in the existing studies. In particular, the dynamics of factor demand is analysed explicitly in the present study. Secondly, empirical results on the substitution structure in the Finnish pulp and paper industry, for which no results at all have been available so far (i.e., for roundwood and pulp inputs), are presented. Furthermore, the recent results of the literature on non-stationary time series (Phillips 1986 and Phillips & Durlauf 1986) and "cointegration" (Engle & Granger 1987) are used to examine the data generation process and to model the dynamics of factor demand.

In the present study, the theoretical basis of the long-run model is derived from neoclassical production theory: the existence of a production function relating output to various inputs; cost-minimizing behaviour on the part of the firms; and duality between production and cost functions. In addition, the short-run dynamic factor demand model is derived in a way which is statistically consistent with the long-run model. This is achieved by applying the so-called Granger Representation Theorem and the results of the cointegration literature.

In the empirical part of the study, factor demand in the pulp and paper industry (ISIC 34111 and ISIC 34112) is analysed using annual time series data from 1960 to 1986. The demand for aggregate inputs, capital, labour, energy and materials (roundwood/pulp), are estimated and the effects of exogeneous technical change are examined.

12. Outline of the study

Chapter 2 gives the background, discusses some of the relevant concepts of the study and reviews the literature pertinent to the study. In particular, the neoclassical framework of the study is presented, the properties of the different functional forms representing production technology are discussed and the various dynamic factor demand approaches are described. The chapter concludes with a brief review of Finnish and foreign empirical studies on factor demand and production structure in the forest industry. In Chapter 3 the theoretical models of the study are presented. First, the static long-run model is described, after which the short-run model is linked to it. In Chapter 4 the institutional framework of the Finnish pulp and paper industry is presented. In particular, the effects of the institutional setting on factor input prices is discussed. The data and estimation methods used in the study are also described. In Chapter 5 empirical models for the pulp and paper industries are derived and the estimation results presented. Finally, Chapter 6 presents some concluding remarks, discusses the implications of the study and suggests possible ways of improving the study in future research. The data and estimation results are presented in detail in the appendices.

2. Modelling factor demand and substitution in the forest industry

The purpose of this chapter is basically threefold. First, to discuss and hopefully clarify some of the relevant concepts used in the study. Secondly, to set the background for the theoretical and empirical framework of the study. Thirdly, to present a brief survey of the (empirical) literature on factor demand in the forest industry.

21. The neoclassical approach

There exists a number of different approaches to modelling factor demand in industry. The most common approaches are based on the neoclassical production theory. However, one could alternatively use the engineering, or frontier (best practice) production function or linear programming approaches to model factor demand (see Heathfield & Wibe 1987 and Hultkrantz 1983), or try to incorporate the factor demand aspect in organizational theories of the firm.[1] The choice of approach is determined mainly by its theoretical consistency, the spesific purpose of the study, the empirical applicability and the availability and quality of the data. For example, the engineering, frontier function and linear programming approaches require cross-section data and engineering information in industrial units and they are particularly suitable for analyses of industrial productivity and the efficiency of technology. Frontier function models refer to best-practice technologies as they exist at a given point of time, while the neoclassical average production function represents the existing technologies of different vintages. That is, the average production function is a reflection of the past best-practice technologies and the existing vintage structure.

The present study is based on the neoclassical approach. The arguments for the choice are as follows: First, the practical reason that the quality and form (time series) of the readily available data were inappropriate for the engineering, frontier functions and linear programming studies. Even if the appropriate data for these approaches had been available, the neoclassical framework would still be preferable because of its relatively easy applicability to empirical factor substitution studies.

Secondly, although it is clear that the very simple and reductionist neoclassical production theory is hardly an exact description of reality, it appears to work better than the alternative theories. In the literature, there are influential theories (e.g., the "managerial" and "satisficing" theories) which have incoprorated important aspects omitted in the neoclassical framework (such as organization patterns, management skills and a number of other institutional factors) and which have questioned the heart of neoclassical theory, the profit maximization hypothesis. However, although these theories may be intuitively appealing, they have been critised for being highly complex and not representing a testable theory (Marris & Mueller 1980). Indeed, these theories have not been as amenable to statistical evaluation as have neoclassical theories. Consequently, if one rejects simple neoclassical theory, testable theoretical hypotheses are very difficult to derive. It appears that (at least currently) the only feasible alternative to neoclassical theory of the representative firm, in the context of present study, would be pure empiricism. In this study, neoclassical theory is taken seriously in the sense that it works as an *approximation* for reality and that the conclusions and implications following logically from the theory are accepted as worth investigating and testing.

Before the relevant literature is discussed, a brief remainder of the concepts used in the neoclassical framework and the issues studied might be helpful in making the exposition more lucid.

Production and cost functions

The technology of a production process defines the technical means whereby input factors are combined efficiently to produce one or more outputs. In neoclassical production theory the efficiency frontier, i.e., the locus of minimum inputs required to produce any given level of output, is represented mathematically by a production function. Consider the following general production function for an industry that produces a single output (Q) from inputs (X):

$$(2.1) \quad Q = F(X)$$

The production function is assumed to satisfy the so-called reqularity conditions, which set the conditions for a well-behaved production function.[2] It summarizes the efficient production possibilities open to the firm. However, the production function gives only the technical constraints; by itself it allows for no testing of economic hypotheses. In order to apply the production function to economic data and to study the relationship between factor prices and factor demand, additional assumptions must be made concerning the firm's economic behaviour. In the basic neoclassical model of the firm, it is assumed that the firm is operating under conditions of perfect competition in input and output markets and that it seeks to maximize its profits while a certain production function (production technology) and exogeneous input and output prices prevail. The problem facing the firm is therefore:

$$(2.2) \quad \max \pi = \max PQ \quad \text{s.t. } Q = F(X)$$

where π denotes profits, P is the output price, Q is the output level, X is a vector of factor quantity levels and F is the production function. Alternatively, if it is assumed that the firm's sales and production decisions are independent of each other it can be thought that the entrepeneur first calculates a minimum cost function and then on the basis of this decides how much to produce. More precisely, the optimization problem facing the firm is to choose its input levels so as to minimize to total costs of producing a given, exogeneously determined, level of output. Thus, the production technology can be expressed by a cost function:

$$(2.3) \quad \min C = \min pX \quad \text{s.t. } Q = F(X)$$

where C denotes production costs and p is a vector of factor prices.

In principle, the minimization of costs is equivalent to a problem of maximization of profits subject to a given output, both yielding the same optimal behaviour. Indeed, maximization of profits implies minimization of costs. In the following discussion, the framework of the study is for the sake of simplicity, presented in terms of the cost function. This is also convenient, since the theoretical model of the present study is based on the cost function approach.[3]

If it is assumed that a firm is minimizing its production costs, there are basically two different ways that can be used to derive systems of input demand equations. First, one may use the concept of production function and derive the demand equations from an objective function using the Langrangean or programming techniques. An alternative method would be to start directly from the concept of cost function and derive the demand equations simply by partially differentiating the cost function with respect to input prices. Thus, the input demand equations are derived without analytically solving the optimization problem. The first method represents the "traditional" neoclassical approach, while the second method represents the application of *Shephard duality* theory to the neoclassical model. The duality property shows that, given a cost function satisfying certain regularity conditions, the cost function can be used to define a production function, which in turn may be used to derive the orginal cost function.[4] The duality between the cost function and the production function establishes the cost function as a "sufficient statistics" for all economically relevant characteristics of the underlying technology (McFadden 1978b). The main advantage of the dual approach is that it provides a much more convinient and simpler way to derive the factor demand equations than the Langrange (primal) method. Some basic properties of the cost functions are presented below. The presentation is based mainly on Diewert (1971, 1987), Fuss (1987) and McFadden (1978b).

Assume that the relevant production

technology can be described by the following general cost function:

$$(2.4)\quad C\,(Q,p,T),$$

where C is the minimum cost of producing output Q, when the firm faces a vector of exogeneous input prices $p = (p_1,\dots\ p_N)$, conditional on an exogeneous index of technical change, T. The cost function is assumed to satisfy the properties outlined in footnote 4. Furthermore, it is assumed that C is twice differentiable in (p, Q). Given differentiability, the cost function has the property known as *Shephard's Lemma*, i.e.,

$$(2.5)\quad \frac{\partial C}{\partial p_i} = x_i$$

where x_i is the vector of factor demands. Thus, the cost minimizing demand for the *i*th input is equal to the partial derivative of the cost function with respect to the price of the *i*th input (for the proof of this, see, Diewert 1987). In addition to the above property, the cost function possesses the property of *symmetry*, i.e.

$$(2.6)\quad \frac{\partial^2 C}{\partial p_i \partial p_j} = \frac{\partial^2 C}{\partial p_j \partial p_i} \quad or \quad \frac{\partial x_i}{\partial p_j} = \frac{\partial x_j}{\partial p_i}$$

The property (2.5) can be used to derive systems of cost-minimizing factor demand functions from arbitrarily specified cost functions, while property (2.6) can provide a test of the underlying cost minimization assumption or can be used to reduce the number of parameters which must be estimated in an econometric application.

Economic effects

Economic effects, such as, substitutability, scale, distribution and technical change, can be examined in terms of the cost function and its first and second derivatives. Because the primary interest in the present study is in the substitution possibilities between inputs, this aspect is discussed here in some detail. The exposition concerning other effects is restricted to merely defining the concept and presenting the relevant formulas which can be used to quantify the particular effect.

The concept of elasticity of substitution was developed separately in the early 1930's by John Hicks and Joan Robinson, who further developed Alfred Marshall's formula for elasticity or derived demand.[5] Hicks defined the elasticity of substitution as the percentage change in the relative amount of the factors employed resulting from a given percentage change in the relative marginal products or relative prices (this is known as the direct elasticity of substitution). Robinson, on the other hand, defined the concept as the proportionate change in the ratio of the amounts of the factors employed divided by the proportional change in the ratio of prices. The above measures were defined for the two-factor case. However, Roy Allen developed (in 1938) measures that can be used in the general n-factor case, known as *Allen partial elasticities of substitution* (σ_{ij}). The definition of this elasticity concept is given below in terms of cost function (4). However, before σ_{ij} is defined, it is helpful to first present the *price elasticity* (e_{ij}) concept.

Conventionally, the price elasticity of factor demand is defined by (using the above cost function notation):

$$(2.7)\quad e_{i_j} = \frac{\partial x_i}{\partial p_j}\frac{p_j}{x_i}\left(= \frac{x_{ij}\,p_j}{x_i}\right) \quad i,j = 1,2,\dots,N$$

where $x_{ij} = x_i(p,\ Q)$. Factor is said to be a (Hicks-Allen) *substitute* for factor *j* if x_{ij} $(=\partial x_i/\partial p_j) > 0$. On the other hand, factor *i* is said to be a (Hicks-Allen) *complement* for factor *j* if $x_{ij} < 0$ ($i \neq j$). The interpretation of these concepts is the following: if a rise in the *j*th factor price, which reduces the use of the *j*th factor (*as* $x_{jj} < 0$), increases (reduces) the use of the *i*th factor for each fixed Q, *i* is a substitute (complement) for *j*.

One important property of price elasticity is that e_{ij} is not symmetric, i.e., $e_{ij} \neq e_{ji}$. However, to overcome this problem, one may use the Allen partial elasticity of substitution measure:

$$(2.8)\quad \sigma_{ij} = \frac{e_{ij}}{S_j},$$

where $S_j = (p_j x_j / \Sigma px)$, i.e., the cost share of the *j*th factor. It can be shown that the $\sigma_{ij} = \sigma_{ji}$ (McFadden 1978a). If σ_{ij} is positive (negative), factors *i* and *j* are substitutes (complements). For the above cost function, the σ_{ij} can be defined as:

$$(2.9)\quad \sigma_{ij} = \frac{C(p,Q)\,\dfrac{\partial^2 C(p,Q)}{\partial p_i\,\partial p_j}}{\dfrac{\partial C(p,Q)}{\partial p_i}\,\dfrac{\partial C(p,Q)}{\partial p_j}} = \frac{C\,C_{ij}}{C_i\,C_j}\ ,\, i\,j = 1, \dots, N.$$

Depending on the type and form of the function used to estimate elasticities, different ways of calculating the elasticities exist. However, since the survey literature on this subject is rich, there is no need to go in to more details here (see, e.g., Hicks 1970, McFadden 1978a and Jorgenson 1986).

Table 1 contains a summary of different economic effects in terms of the cost function. The *elasticity of scale* (μ) is the ratio of the proportionate increase in cost to the proportionate increase in output. The returns to scale can be *constant, increasing, decreasing*, depending on whether $\mu = 1$, $\mu > 1$, $\mu < 1$, respectively. The *distributive share* (S_i) measures the cost share of factor *i* in the total cost of producing output Q. The *own price elasticity* (e_{ii}) measures the precentage change in the use of input *i* resulting from a percentage change in its price. The *rate of technical change* (T) measures the effects of disembodied technical progress on the costs, input demand and factor shares. The effects are analysed in terms of the partial derivatives of the cost function with respect to the trend variable. If technical change affects all factors equally so that the input-mix remains unaffected, it is said to be Hicks neutral. In this case technical progress has no effect on the cost shares of the various inputs, i.e., $\partial S_i/\partial T = 0$. On the other hand, technical changes is said to be factor i-using if $\partial S_i/\partial T = 0$ and factor *i*-saving if $\partial S_i/\partial T < 0$.

Table 1. Economic effects and their relation to the cost function.

Economic effect	Cost function formula	No.of distinct effects
Cost level	$C = C\,(p, Q, T)$	1
Elasticity of substitution	$\sigma_{ij} = (C - C_{ij})/C_i\,C_j$	N(N - 1)/2
Returns to scale	$\mu = (C/Q)/C_q$	1
Distributive share	$S_i = (C_i\,p_i)/C$	N - 1
Own-price elasticity	$e_i = (p_i\,C_{ii})/C_i$	N
Rate of technical change	$T = -C_t/C$	1
Bias of technical change	$(\dot{S}_i/S_i) = C_{it}/C_i - C_t/C$	N

Note: Subscripts denote the partial derivatives of the cost and factor share functions.

22. Functional forms representing production technology

In order to be able estimate the economic effects, one has to choose a specific functional form for the production or cost function. The brief and simple presentation of the different features of production technology in the previous section showed that it is important to separate the effects of changes in substitution possibilities, scale economies and technical change from each other. Also, it is important in the empirical application to represent the production technology in a way that, a priori, restricts the economic effects as little as possible. How well this can be done depends critically on the specific functional form chosen to estimate the production technology. For example, if one were to choose a restrictive functional form, then in the event of a hypothesis being rejected, it could be argued that it is the functional form which is being rejected. By choosing a very general form the results are made robust in this respect. Indeed, the main task of applied neoclassical production economics has been to develop functional forms which are very general and allow the simultaneous estimation of the substitution, scale and technical change parameters. Some of the main developments in the literature are discussed below.

Research on different functional forms has progressed significantly since the introduction of the two factor Cobb-Douglas production function (1928), which included as a maintained hypothesis constant returns to scale, unitary elasticity of substitution and neutral technical change. After the introduction of the Cobb-Douglas production function, the major innovation in functional form was the "constant elasticity of substitution" (CES) function by Arrow et al. (1961), which allowed elasticity of substitution to be different from one. However, the CES function is still rather restrictive in that it constrains the elasticity of substitution to be constant in the sense that it does not change with changes in relative prices of factor inputs. Attempts to relax this stringent requirement led to the developement of the variable elasticity of substitution (VES) function, in which elasticity and returns to scale depend on the output and/or input mix (see, e.g., Zellner & Revankar 1969). However, a major innovation was the formulation of the "flexible functional forms" (FFF), which do not *a priori* impose restrictive constrains such as homotheticity, constancy of substitution, additivity, etc, but can reflect any combination of economic effets at a particular point. Thus, FFFs constitute a major advance in comparison to the functions traditionally used. In empirical factor demand studies, the application of FFFs has become popular after the introduction of the "translog" (Christensen, Jorgeson & Lau 1971) and "generalized Leontief" (Diewert 1971) functions.

Diewert (1987) has suggested four different criteria for choosing the functional form for a cost function. First, the function should be *flexible*, i.e., the functional form should have a sufficient number of free parameters to be able to provide a second order approximation to an arbitrary twice continuously differentiable function with the appropriate theoretical properties. For example, if we have N variables, the condition requires 1 + N + N(N + 1)/2 free parameters unless there are special restrictions on the function that is being considered. Accordingly, if N equals 5, then a function requires 21 parameters. Secondly, the function should be *parsimonious*, i.e., the functional form for the cost function should have the minimal number of free parameters required to have the flexibility property. Thirdly, the function should be *linear*, i.e., the unknown parameters of the cost function should appear in the system of estimating equations in a linear form in order to avoid non-linear estimation. Finally, the cost function should be *consistent* with the properties that determine the existence of a well-defined cost function (see footnote 4).

It can be shown (see Diewert 1987) that the translog and generalized Leontief functions do have the first three properties, i.e., they are flexible, parsimonious and linear. However, there has recently been some criticism of FFFs for not being able to incorporate the consistency property in empirical applications (see, for example, Caves & Christensen 1980, Guilkey et al. 1983, Barnett & Lee 1985, Despotakis 1986, and Diewert & Wales 1987, 1988). When FFFs were originally proposed, they were intended to be used only in those cases in which the specified function satisfies the "consistency property", i.e., the regularity or the "theoretical curvature" conditions at every data observation point (see, footnotes 2 and 4.) However, as Barnett & Lee (1985) observe, "Experience soon indicated that the available flexible functional forms tended to violate the maintained regularity conditions at many points of most data sets. Since that fact became evident, information about the frequency of violation of regularity conditions nearly ceased appearing in the applied literature using flexible functional forms" (op. cit. 1421). The general result (of the Monte Carlo simulations) has been that the translog and generalized Leontief functions behave well locally, but poorly globally. That is, they tend to satisfy the regularity conditions at some data points, but not at every data point. However, since statistical inferences in econometrics depend upon the behaviour of the model at every data point, it is evident that the deficiencies in FFFs' global properties reduce their robustness.

The above weakness of the "traditional" FFFs has led to the development of new functional forms which have better global properties. Gallant (1981) has developed the "Fourier" function, Barnett et al. (1985, 1987) have come up with the "minflex Laurent" functions and Diewert & Wales (1987) have developed the "generalized McFadden" function. The different. properties of these models stem from their underlying mathematical functional form and the imposition of concavity restrictions. The traditional translog and generalized Leontief models are second order Taylor series expansions, the Fourier model is an expansion of the Fourier series, while the minflex Laurent model is a special case of a second order Laurent series expansion. The global properties of these series are very different. For example, because the remainder term of a Laurent expansion varies more gradually than that of a Taylor series, the subset of the parameter space within which the minflex Laurent model is everywhere well-behaved is larger than in models based on Taylor series.[6] On the other hand, the generalized McFadden function is still based on Taylor series, but better global properties are obtained by imposing the appropriate curvature conditions globally (imposing negative semidefiniteness on the Hessian matrix).

However, the major problem with these new generation of FFFs, or the imposition of negative semidefiniteness, is that they require nonlinear estimation techniques. Furthermore, these models tend to have more parameters, thus requiring more data. In addition, as Diewert & Wales (1987) have noted, the potentially serious problem with the procedure of imposing negative semidefiniteness on the parameter matrix is that it can destroy the flexibility property of the translog cost function. They conclude that: "In general, the use of the Jorgenson-Fraumeni procedure for imposing concavity will lead to estimated input substitution matrices which are in some sense "too negative semidefinite"; i.e., the degree of input substitutability will tend to be biased in an upward direction" (op.cit. p. 48). Indeed, because of the above problems, there have been very few applications of the new generation FFFs.

Translog cost function

Since the discussion below on studies of factor demand in the forest industry (section 25) is largely based on the translog cost function applications and because the model in the present study is based on this functional form, it is convenient to present the function here. The translog cost function, which is a local second order approximation of any arbitrary cost function, can be expressed in logarithms as below:

$$(2.10)\quad lnC\,(p,Q) =$$

$$\alpha_0 + \sum_{i=1}^{N}\alpha_i \ln p_i + \alpha_Q\, lnQ + \alpha_T T + \frac{1}{2}[\sum_{i=1}^{N}\alpha_{ii}\,(\,lnp_i\,)^2$$

$$+\ \alpha_{QQ}\,(\,lnQ\,)^2 + \alpha_{TT}\,(\,T\,)^2\,] + \sum_{i=1}^{N}\sum_{j=1}^{N}\alpha_{ij}\, lnp_i\, lnp_j$$

$$+\ \sum_{i=1}^{N}\alpha_{iQ}\, lnp_i\, lnQ\ +\ \sum_{i=1}^{N}\alpha_{iT}\, lnp_i\, T\ +\ \alpha_{QT}\, lnQT$$

where

$$(2.11)\quad \sum_{i=1}^{N}\alpha_i = 1\,;\ \sum\alpha_{ij} = 0\,;\ \alpha_{ij} = \alpha_{ji}\,;\ i,j = 1,\ldots,N$$

$$\sum_{i=1}^{N}\alpha_{iQ} = 0\,;\ \sum_{i=1}^{N}\alpha_{iT} = 0$$

Restrictions in (2.11) are imposed to ensure that C (p, Q) is homogeneous of degree one with respect to p and that Hessian matrix is symmetric. i.e., $(\partial^2C/\partial p_i\partial p_j) = (\partial^2C/\partial p_j\partial p_i)$. These restrictions on the cost function are imposed on (2.10), since they are implied by the regularity conditions (see footnote 4). Differentiating both sides of (2.10) with respect to the logarithm of the *i*th input price, lnp_i; for $i = 1,\ldots, N$ and applying Shephard's lemma yields the following system of equations:

$$(2.12)\quad S_i \equiv \frac{\frac{p_i\,\partial C}{\partial p_i}}{C} = \frac{p_i X_i}{C} = \alpha_i + \sum_{j=1}^{N}\alpha_{ij}\, lnp_j + \alpha_{iQ}\, lnQ + \alpha_{iT}\, T$$

The characteristics of the underlying production technology, in terms of price and substitution elasticities, can be derived for the translog function using the following formulas. First, from (2.10) we obtain:

$$(2.13)\quad \alpha_{ij} = \frac{\partial^2 lnC}{\partial lnp_i\,\partial lnp_j} = p_i\, p_j \frac{\partial}{\partial p_i}(\frac{1}{C}\frac{\partial C}{\partial p_j}) \qquad ,\text{ if } i \neq j$$

$$= p_i^2 \frac{\partial}{\partial p_i}(\frac{1}{C}\frac{\partial C}{\partial p_i}) + (\frac{1}{C}\frac{\partial C}{\partial p_i})\, p_i$$

Then recalling $\partial C/\partial p_i = x_i$ (Shephard's lemma) and from (2.8), we obtain the following formula for computing the Allen elasticities of substitution (σ_{ij}) using the values of the α_{ij}'s estimated from (2.12),

$$(2.14)\quad \sigma_{ii} = \frac{\alpha_{ii} + S_i^2 - S_i}{S_i^2}$$

and

$$\sigma_{ij} = \frac{\alpha_{ij} + S_i\, S_j}{S_i S_j}$$

This formula can also be obtained by applying (2.10) to (2.9). Since S_i can change from time to time, the σ_{ij}'s need not be constant (unlike the case of CES functions). The own-price elasticities (e_{ii}) and cross-price elasticities (e_{ij}) of demand for inputs can be calculated as:

$$(2.15)\quad e_{ii} = S_i\,\sigma_{ii}$$

and

$$e_{ij} = S_j\,\sigma_{ij}$$

Since $\alpha_{ij} = \alpha_{ji}$ the Allen elasticities are symmetric, but the cross-elasticities (e_{ij}) are not. It should be stressed that e_{ij} is the output-compensated cross-price elasticity and gives a measure of pure technical substitution between inputs *i* and *j*. However, in a recent study, Capone & Elzinga (1987) have derived a method by which the full elasticity, which includes an output effect, can be calculated. Theoretically, this elasticity is derived from the "Slutsky" formula, where changes in input-use resulting from changes in another input's price are separated into substitution and output effects (see op.cit.):

$$(2.16) \qquad \frac{\partial x_i}{\partial p_j} = \frac{\partial x_i}{\partial p_j}_{\bar{q}} - x_j \left(\frac{\partial x_i}{\partial C}_{\bar{p}}\right)$$

Multiplying both sides of (2.16) by p_j/x_i gives the equation for full elasticity, E_{ij}.

$$(2.17) \qquad \frac{p_j}{x_i}\frac{\partial x_j}{\partial p_j} = \frac{p_j}{x_i}\frac{\partial x_i}{\partial p_j}_{\bar{q}} - x_j \left(\frac{\partial x_i}{\partial C}\right)_{\bar{p}} \frac{p_j}{x_i}$$

$$E_{ij} = e_{ij} - \frac{x_j p_j}{x_i}\left(\frac{\partial x_i}{\partial C}_{\bar{p}}\right)$$

Given $x_i = S_i C/p_i$ and assuming a *locally homothetic* production function ($\partial S_i/\partial C = 0$), Capone & Elzinga derive

$$(2.18) \qquad \frac{\partial x_i}{\partial c}_{\bar{p}} \frac{S_i}{p_i} = \frac{x_i}{c}$$

and consequently

$$(2.19) \qquad E_{ij} = e_{ij} - S_j$$

which is easily derivable once the cross-price elasticities have been calculated. It should be noted that if the local homotheticity assumption does not hold, the measured elasticity of demand, E_{ij}, will be biased to the extent that $\partial S_i/\partial C \neq 0$, as can be seen from the formula

$$(2.20) \qquad E_{ij} = e_{ij} - S_j\left(1 - \frac{C}{S_i}\frac{\partial S_i}{\partial C}\right)$$

To the extent that S_i changes gradually as cost increases, this bias will be very small.

Finally, the effects of technical change in the translog cost function can be analysed using the parameters α_{iT}. Technical change is said to be factor *i*-using if $\alpha_{iT} > 0$, *i*-neutral if $\alpha_{iT} = 0$ and *i*-saving if $\alpha_{iT} < 0$.

23. Dynamic models

The majority of studies of factor demand based on FFF cost functions have been estimated with time-series data (generally annual) for an individual country. Before the 1980's, it was common to base these studies on the assumption of full static equilibrium. In other words, it was assumed that the data approximated observations of different long-run equilibrium and that all inputs were fully flexible and optimized at each observation. However, during the last decade or so, this rather stringent assumption has often been relaxed and instead partial static equilibrium and dynamic factor demand models have been used. The purpose of this section is to examine the different approaches that can be used to model the adjustment to short-run disequilibrium in factor demand. The discussion starts by looking at the "restricted cost function" method, after which the "cost of adjustment" models are discussed. The section concludes by describing a new approach to modelling the dynamics of factor demand, which is based on the "error correction model" (EMC) and the results of the "cointegration" literature. This approach is also used in the present study.

In the restricted cost function models it is assumed that certain factors of production (typically capital) may be fixed in the short-run so that they cannot readily adjust to changes in prices or output demand. The variable inputs are then optimized conditional on the levels of the fixed input. The short-run input elasticities are obatained by taking partial derivatives of the demand equations for the variable inputs with respect to their prices, holding the fixed factor constant. The long-run elasticities can be derived by using the envelope condition, i.e., for a given level of output the short-run and long-run cost curves will be tangent at the point where the fixed factor is at its equilibrium level or where the shadow value of the fixed factor equals its price (see, e.g., Dargay 1987). The main advantage of the restricted cost function approach is that both short- and long-run demand relationships can be estimated without explicitly specifying the adjustment process. However, the major drawback of the restricted cost function is that no information is given either as to the speed of adjustment to long-run equilibrium or to the factors influencing the adjustment process. Also, there is no theoretical justification for the lag-structure employed. Finally, in empirical applications the substitution elasticities for the quasi-fixed factor are rather difficult to calculate, since the shadow value of the fixed factor has to be determined first (for recent literature on this approach, see, e.g., Berndt & Fuss (eds.) 1986 and Dargay 1987).

In the dynamic adjustment cost approach, instead of just assuming some factors to be quasi-fixed in the short-run, the inflexibility of these factors is modelled explicitly, i.e., the cost of adjustments are an integral part of the underlying economic theory. The adjustment costs can be either internal or external. Internal costs refer to the output the firm forogoes by diverting resources from production to investment activities (e.g., planning and installation), while external costs usually arise when the firm is a monopsonist in the market for factor input and faces a rising supply price for it. Adjustment costs are almost always assumed to be increasing at the margin, i.e., strictly convex. This is because if adjustment costs are constant or diminish at the margin, the firm will, as a rule, immediately close any gap between desired and actual levels of the quasi-fixed factor and the lagged adjustment disappears. In the adjustment costs models, one can then distinguish between short-run costs, which are given by the relative prices of the flexible factors and ajdustment costs of the quasi-fixed factors, and long-run costs, given by the relative prices of all factors. In the long-run the relevant dynamic problem of the firm is to minimize the present value of the future costs. Short-run elasticities are calculated holding the quasi-fixed factor at a constant level and the long-run elasticities are calculated on the assumption that the quasi-fixed factor has fully adjusted to its new desired level (for recent literature on this approach, see, e.g., Pindyck & Rotemberg 1983, Prucha & Nadiri 1986, Maccini 1987 and Pfann & Verspagen 1989).

The advantage of the adjustment costs approach is that it incorporates the adjustment mechanism in the underlying economic theory. Also, it provides a method for analysing the investment behaviour of the firm. However, the major weakness of the approach is the assumption of convex adjustment costs. Although there exist numerous arguments for strictly convex adjustment costs, none of them can be regarded as applying in general. The implausibility of the strictly convex functional form has already been shown in Rothschild (1971).[7] Also, Schankerman & Nadiri (1986) have noted that convex adjustment costs rule out potentially important assymmetries regarding the costs of investment and disinvestment and that there may be various reasons for divergence between the actual and static equilibrium levels of fixed factors which cannot be summarized adequately by an adjustment cost model, such as regulatory restrictions, credit rationing and other institutional rigidities. Indeed, in a recent survey of the adjustment costs literature Maccini (1987) concludes that, "While the incorporation of adjustment costs into the theory of the firm has generated much insight into investment behaviour, there is some disquieting uneasiness that the theoretical developments may rest on a weak foundation" (op.cit. p. 25). In spite of this, the quadratic adjustment cost assumption is inherent in most derived dynamic empirical factor demand models. For example, all the dynamic models of producer behaviour discussed in the recent survey by Jorgenson (1986) are based on strictly convex adjustment costs. One of the reasons why the quadratic adjustment costs assumption has been so popular in time series applications is probably the fact that models which do not make this assumption tend to have poor statistical properties (low Durbin-Watson values). However, some recent results concerning the properties of estimators in models with time dependent observations (i.e., the results from the literature on non-stationary time series and cointegration, see chapters 3 and 4), indicate that the rejection of models which do not employ quadratic adjustment costs may have been based on false statistical inference.

Instead of using the above "conventional" approaches in modelling the dynamics of factor demand, one could alternatively use the *error correction models* and the results of the *cointergation* literature.[8] Underlying this approach is the general criticism that conventional econometrics pays little attention to the time series features of economic data, i.e., the economic models are specified using only the information provided by economic theory. Indeed, economic theory as such is regarded as being incapable of describing the dynamic behaviour of many economic variables, and one should instead use the information included in the underlying time series data to model the dynamic adjustment process. The ECMs are based on the idea that there exist a long run constant ("equilibrium") relation between the relevant economic variables which is consistent with economic theory and around which there is short run stochastic noise which economic theory cannot explain. On then incorporates in a dynamic equation variables (in differences) which cause deviations from the equilibrium relationship in the short run, but one also incorporates in the equation a mechanism which accomplish to restore the long run constant relationship. The premise of the ECM approach to this kind of dynamics is that long run proportionality of the above kind is a feature that one should expect of economic variables. Furthermore, recent developments in the study of non-stationary time series and cointegration has strengthened the basis of the ECMs. The claim that there generally exist long-run relationships between variables may now be recognized as the claim that economic variables are cointegrated. Engle & Granger (1987) have shown that, if two or more variables are cointegrated, there must exist an ECM linking these variables (see Chapter 3).

Although, the ECMs *as such* leave open the questions of what kind of economic theory mechanism generate the dynamics of the model and are thus less informative in this respect than the adjustment costs models, they do not rest on a such ambiguous assumptions.[9] ECMs have recently become very popular in econometric modelling, but there have been very few applications in flexible functional form factor demand studies. Holly & Smith (1989) have applied the ECM using a dynamic translog cost function factor demand model, but they do not use the results obtained in the cointegration literature. However, in an unpublished study, Hetemäki, M. (1987) uses the cointegration approach in the context of a Generalized Leontief profit function factor demand model.

24. Previous studies

The developments in applied neoclassical production economics discussed in the previous section have been fairly quickly adapted in the international forest economics literature. However, the most recent developments in functional forms, dynamic modelling and time series econometrics have not yet found their way to forest economic applications. In order to put the present study in perspective, some of the recent studies using neoclassical production theory to study factor demand in the forest industry are discussed below. The brief review of the literature will help to show how the present study is related to earlier ones and what new information it may add to the present body of knowledge. A number of empirical studies from Finland and other countries are described.

Finnish studies

Apparently, the first economic study in Finland which included an analysis of factor substitution possibilities in the forest industry, was a time series study by Simula (1979). The study is primarily concerned with the productivity of the Finnish forest industries at sectoral level, but also includes an analysis of factor substitution possibilities. In Simula (1983), the previous study was extended to a cross-section framework. Törmä (1986, 1987) and Törmä & Loukola (1986) have carried out an extensive and detailed study of factor substitution in Finnish manufacturing both at the aggregate and sectoral level. Törmä & Loukola also includes analyses of factor substitution possibilities in the Finnish wood and paper products industries.

Simula (1979) analysed the productivity of the various sub-sectors of the Finnish pulp and paper industry, using annual time series data from 1954—1974. The study consists of estimations of Cobb-Douglas (CD), Constant Elasticity of Substitution (CES), Variable Elasticity of Substitution (VES) and Translog *production* functions for the different sub-sectors of the industry. The functions are static and in value added form, i.e., material inputs are omitted from the analysis. Simula's results and discussion concerning the factor elasticity of substitution are rather limited. His results suggest that some substitution possibilities existed in the pulp and paper industries before the mid-1960's, but that since then substitution possibilities between capital and labour have diminished and the production technology appears to have become fixed.

Simula (1983) analysed the forest industries at the sectoral and plant level, using cross-section data from 1974. He estimated static CD, CES and VES production functions with three inputs, capital, labour and materials. The material input was estimated in aggregate form and thus no separation between the chemicals, energy and roundwood components was made. Therefore, information concerning the substitution possibilities between these input components and other production factors could not be produced. According to the results, the cross-section models produced substantially higher estimates for elasticity of substitution than those derived from time series models (e.g., Simula 1979). Simula suggests that the result is plausible if time series estimates are interpreted as short run relationships and the cross-section results as reflecting the long term situation. On the other hand, according to Simula the very high (statistically significant) elasticity parameters for the pulp and paper branches do not seem to be reasonable, since he assumes, a priori, that the production technology is rather rigid in these industries. However, this interpretation of the results appears to be partly biased, because Simula does not recognize all the possible substitution channels.[10]

Törmä & Loukola (1986) studied the elasticity of demand for factors of production of the different sectors of Finnish manufacturing industry, including the manufacturing of wood and wood products (ISIC 33) and paper and paper products (ISIC 34). They estimated a *nonhomothetic* generalized Leontief cost-function model using annual time series data from 1960—1981.[11] The Leontief function, rather than the translog function, was used because the authors considered it to be particularly useful in their policy simulations analysis (the Leontief function includes the input *quantity* as a dependent variable). The estimated cost function was in gross output(cost) form, thus including capital, labour and intermediate inputs. Intermediate inputs were divided into energy and raw materials inputs while the energy input was further divided into electricity and fuels inputs. Finally, the fuels input was derived using a submodel technique (see Fuss 1977) which allowed the separate analysis of the fuels input components (district heating, light fuel oil, heavy fuel oil and coal). The estimation method was Zellner's iterative three-stage least square method (ZI3SLS) (see, e.g., Pinkdyck & Rubinfeld 1981). The results indicated that the Allen elasticities of substitution were not different from zero between capital and labour, capital and electricity and materials and electricity. On the other hand, the results showed significant substitution possibilities between labour and materials and electricity and materials. Capital and materials were shown to be complements. The own-price elasticities for electricity, labour and matarials varied between −0,21 and −0,46. The own-price elasticity of capital was +0.06, indicating violation of the concavity condition.

The above studies have some important restrictions, which reduce their usefulness in analysing factor demand in the pulp and paper industries. First, the roundwood component is not modelled separately from the materials input. This treatment of intermediate inputs effectively rules out changes in the cost of forest resources as a cause and source of production structure in forest-based industries. Secondly, all the studies model factor demand in a static framework without considering dynamic adjustment. Furthermore, the properties (stationary) of the underlying time series data are not examined in Simula (1979) or in Törmä & Loukola (1986). Finally, Simula's models are based on restrictive functional forms.

Foreign studies

The following discussion on foreign studies is mainly restricted to some of the recent studies which have applied new developments in production economics (felxible functional forms and duality theory results) to model factor demand in the forest industry. Furthermore, only the studies dealing with the pulp and paper industry in Canada, the United States and Sweden, where the production technology is most similar to Finland, are presented here. Three studies, which use the translog cost function approach and can be considered to give a representative picture of the "state of the art" of the subject, are briefly discussed (Sherif 1983 (Canada), Stier 1985 (USA) and Wibe 1987 (Sweden)).[12] These studies analyse the pulp and paper industry in a static framework. There are some studies which do use the conventional dynamic approaches discussed in Section 23. to model factor demand in the forest industry, but they are all applied to the lumber and/or ply wood industries. A few words will nevertheless be said about these studies.

The purpose of Sherif (1983) is to assess the effect of changes in prices of factor inputs and technical progress on the average cost of production and demand for factor inputs in the Canadian pulp and paper industry 1958—77. She treats the industry as a single output firm and estimates a nonhomothetic translog cost function and factor share demand equations jointly as a multivariate system using the ZI3SLS-method. The cost function includes capital, labour, energy and wood inputs and a linear time trend. According to the results, the majority of the factors are substitutes, but slight complementarities exist between wood and labour and between capital and energy. All the own-price elasticities are significantly negative, the energy input being most sensitive to changes in its own price. In addition, the results indicated the existence of economies of scale, a 10 % increase in output leading to a 6.5 % increase in total cost. Finally, the results indicated that the pulp and paper industry has been wood and labour saving and capital and energy using.

Stier (1985) begins his study with a quotation from the U.S. Forest Service Report (1982), which concluded that "the pulp and paper industry has a consistent historical record of cost-saving technical improvements at all levels of processing" (op. cit., p. 803). In order to gain a more complete understanding of how this cost-saving (production technology) record has been established, Stier estimates a homothetic translog cost function for the aggregate U.S. pulp and paper industry, using annual time series data for the period 1948—76. In particular, Stier's objective is to study substitution among labour, wood and reproducible capital inputs, returns to scale, price elasticity of derived demand for factor inputs and the nature of technological progress.

Like Sherif, Stier estimates the cost function and the factor share equations as a joint system, using the ZI3SLS method. The model orginally also had an energy input, but because its inclusion meant that the cost function did not meet the concavity requirements of neoclassical cost function, it was omitted from the final model. The structure of the model is very similar to the one used by Sherif.

Stier's results indicated that both the Cobb-Douglas and Leontief-type fixed production technology structure and the Hicks neutral technical change hypotheses should be rejected. However, because of the low factor substitution elasticities and the related price elasticities of derived demand for inputs, the industry's production technology is characterized by limited opportunities for substitution among factors. According to the results, technological progress in the U.S. pulp and paper industry during the estimation period tended to conserve labour relative to capital and wood. This trend has resulted in a more than two-fold increase in the capital/labour ratio over the period studied. Finally, scale economies were found to be significant and somewhat larger than in Sherif's study.

Wibe's (1987) study was motivated by the following observation on the Swedish pulp and paper industry: "The technology of the pulp and paper industry has changed dramatically during the last 30 years. New products and new processes have emerged and changing factor prices have strongly affected the chosen technology. In addition lower transport costs and better technology have made it possible and profitable to build larger and larger plants" (op. cit. p. 1). Thus, Wibe's objective is to study how the technology of the chemical pulp industry is affected by changes in factor prices, by the time of observation, and by scale and capacity utilization. In particular, he is interested in separating empirically the effects of increased scale and technological progress.

Wibe uses a translog cost function to investigate these questions during the period 1952—82. The data is based on combined time series aggregated data and cross-sectional plant data. The variables in the model include capital, labour, material and energy inputs, and degree of capacity utilization, size of the plant and time of observation variables. Wibe used pooled cross-section time series data in order to reduce the possible multicollinearity between the variables. In addition, the system of share equations was estimated using *relative* prices (the price of capital was chosen as the numeraire). As Wibe seeks to estimate a *firm* (and not an industry) cost function, he assumes that the aggregate time series data for capacity utilization, prices and technology are representative for the "average firm". Accordingly, the size measure used is the *average plant size*, calculated as the ratio between total output and total number of plants (47).

Wibe's results can be briefly summerized as follows: 1) Capital and labour are complements, and labour is very insensitive to changes in its own price. 2) Capital is a substitute for both energy and material. 3) The relationship between energy and material changed during the estimation period. For the period 1952—67, it was not possible to substitute material for energy and the Allen partial elasticity of substitution was zero. This changed at the end of the period and in the years 1978—1982 there was clear evidence that material and energy were substitutes in production. 4) When plant size increases, the technology applied appears to be more capital-intensive while the use of energy and labour falls. The consumption of material is more or less invariant w.r.t. scale. 5) Wibe's results indicate the existence of strong scale economies. A 1 % increase in plant size can be expected to reduce unit costs by 0.1—0.15 %. Since the average plant size has grown at a rate of about 5.4 % annually, it can be assumed that the increase in size has caused a drop in unit cost of 0.5—0.7 % per year. 6) Technological progress is capital, energy and material using, and labour saving. 7) The economic impact of technological progress declines over time. Changes in technology and scale taken together caused a decrease in unit costs by about 60 % during the estimation period.

The above studies and most of the other applications of the translog function to factor demand in the forest industry have been based upon the assumption of observed static equilibrium or instantaneous factor adjustment. Recently, however, studies by Merrifield and Singleton (1986), Abt (1987) and Meil et al. (1988) have used a dynamic factor demand approach. The incorporation of the dynamic nature of factor demand is important, since the assumption that the industry remains on its least-cost expansion path over time is not realistic and is often unjustified. For example, Meil et al. state that, "total cost minimization is an unlikely outcome for the Canadian lumber industry, which is known to operate frequently at something less than full capacity... due to the highly cyclical nature of commodity lumber markets. Second, the implicit assumption of full or complete adjustment of the input mix to changing factor prices such that the industry remains on its least-cost expansion path is implausible for many production processes" (op. cit., p. 89).

All the three studies assume that adjustments in capital are impossible in the short run. Because capital is fixed in the short run and may not be at its equilibrium level, the other substitutable or complementary inputs are also unlikely to be at their optimal levels. The studies by Abt (1987) and Meil et al. (1988) use a restricted cost function approach, which does not allow the calculation of the substitution of the other inputs for the fixed factor (capital). Merrifield and Singleton (1986), on the other hand, use the internal cost of adjustment model. The structure of their model is based on the work of Berndt, Fuss, and Waverman (1977, 1980), which is itself an extension of the Lucas (1967) and Treadway (1971, 1974) models.[13] According to the model, cost-minimizing short-run variable input demands are derived in terms of the level of output, input prices and the level of quasi-fixed capital. The adjustment process of the capital input is given in the context of a flexible accelerator model.

In summary, there exists a relatively rich foreign literature on factor demand in the pulp and paper industry, in contrast to the rather few Finnish studies. Theoretical and empirical advances in economic theory and econometrics have been adapted fairly quickly in the forest economics literature. However, some recent developments in time series econometrics and in flexible functional form cost (profit) functions have not yet found their way into forest economics applications (see Sections 23. and 25.).

Footnotes

1. A number of organizational theories of the firm appeared in the 1960's. For example, in the class of optimizing models, W.J. Baumol, O.E. Williamson, and R. Marris developed independently the so-called managerial theories of the firm, in which the firm's management seeks to maximize growth (rather than profit), subject to a minimum profit constraint in order to keep the shareholders happy. In contrast, another set of theories was formulated based on the idea that firms (or managament) cannot optimize because they have neither the information nor the computational capacity to do so, but at most something approaching H. Simon's "bounded rationality" (or a satisficing objective). The managerial, satisficing and other theories of the firm are discussed, for example, in Marris, R & Muller, D.C. (1980), "The Corporation, Competition, and the Invisble Hand", Journal of Economic Literature , vol. XVIII; 32—63, and in Archibald, G.C. (1987), "Theory of the firm", in Eatwell, J., Milgate, M. & Newman, P. (eds.), vol. II, 357—362. A recent survey of the organizational theories of the firm can be found in Milgrom, P. & Roberts, J. (1988), "Economic theories of the firm: past, present, and future", Canadian Journal of Economics, XXI, no. 3; 444—458.

2. The regularity conditions, which set the conditions for a well-behaved production function, are (Diewert 1971):

i) F is a real valued function of n real variables $X = (x_1, x_2,..., x_n)$ defined for every $X \geq 0$ (where 0 is an n by one vector with each component equal to zero), and F is finite if each component of X is finite. In other words, every finite bundle of inputs gives rise to finite output.

ii) F(0) = 0, and F is a nondecreasing function in X. The first part of this condition states that, given zero levels of all inputs, all we can produce is zero output. The second part tells us that, given more of any input, output does not decrease.

iii) $F(X^n)$ tends to plus infinity for at least one nonnegative sequence of vectors (X^n). That is, every positive output level is producible with some input combination.

iv) F is continuous from above or F is a right continuous function. In particular, this condition states that if F is a continuous function, then in particular it will be continuous from above.

v) F is quasiconcave function of Ω (where Ω is the nonnegative orthant in n dimensional Euclidean space). This condition is a generalization of the neoclassical condition that F must be concave function, which in turn is a generalization of the classical condition that the production function exhibits diminishing returns with respect to any input.

3. It may be noted that the cost function approach has one desirable advantage in empirical industry or industrial sector-level studies compared to the production function approach. The factor demand functions derived from the cost function have input *prices* as explanatory variables, while in the production function the explonatory variables are input *quantities*. It seems to be fairly realistic to assume that the prices firms pay for their inputs, or the price changes over time, are roughly equal per input unit used. However, to assume that firms use the same quantity of factor inputs is clearly unrealistic. Indeed, it would imply that firms within the industry (or industrial sector) are of equal size and identical, apart from differences in efficiency. Thus, the problems of aggregation of individual firms to the industry (or industrial sector) level are notably less serious if one uses the cost function rather than the production function approach.

4. Samuelson, P. 1947. Foundations of Economic Analysis. Harvard University press., Shepherd, R.W. 1953. Cost and Production Functions. Princeton University Press. Diewert (1971, pp. 484—490) discusses the regularity conditions which allow duality between the production and cost functions. The conditions for the production function are those presented in footnote 2. Deiwert shows that these conditions imply the following constraints for the cost function:

i) h is a positive real valued function, defined and finite for all finite, $Q > 0$, $P >> 0$ (>> means strictly greater). That is, any positive and finite output level implies a positive and finite cost level provided that factor prices are positive.

ii) h is a nondecreasing left continuous function in Q and tends to plus infinity as Q tends to plus infinity for every $P > 0$. Thus, increasing the output level cannot lower production costs.

iii) h is a nondecreasing function in P. This states that increasing factor prices cannot lower production costs.

iv) h is (positive) linear homogeneous in P for every $Q > 0$. This is the familiar condition saying that multiplying all factor prices by some factor raises production costs by the same factor.

v) h is a concave function in P for every $Q > 0$. This condition states that if the price of a factor rises, costs will never go down, but will go up at a decreasing rate. This is because as one factor becomes more expensive and other prices stay the same, the cost-minimizing firm will shift away from it to use other inputs (see Varian 1978, p. 29).

5. Hicks presented his definition of the elasticity of substitution in "Theory of Wages" (1932) and Robinson her definition in "Economics of Imperfect Competition" (1933). For an account of the history of the concept, see Eatwell et al. (1987), vol II: 127—128.

6. The different properties of FFFs stem from the fact that the Laurent series remainder term is the sum of the two terms which always move in opposite directions. By contrast, the remainder term of the Taylor series expansion is that of an inherently local approximation, since the remainder rapidly varies from zero at the centre of approximation to large values of the radius of convergence (see Barnett & Lee 1985).

7. Indeed, the adjustment costs may very well be linear, concave or unstable, rather than convex. For example, it seems implausible that the disruption associated with installing seven new machine tools should necessarily be forty-nine times as large as the disruption associated with installing one new machine tool. Furthermore, there is evidence that adjustment costs may not be stable over time (see, e.g., Pfann & Verspagen 1989).

8. Error correction models were introduced in economics by Phillips, A.W. 1954. Stabilization Policy in a Closed Economy. Economic Journal 64. The first econometric application of the error correction structure was apparently the study by Sargan, J.D. 1964. Wages and Prices in the United Kingdom: A Study in Econometric Methodology, in Hart, P.E., Mills, G. & Whittaker, J.K: (eds.),. Econometric Analysis for National Economic Planning. For a recent discussion of ECMs and cointegration, see Aoki (ed.) 1987.

9. In fact, it is quite common in empirical applications to derive the error correction model by invoking some kind of adjustment costs. However, by omitting any adjustment costs specification the economic content of the model obviously suffers, though, on the other hand, one avoids making unfounded assumptions.

10. Althought Simula (1983) acknowledges that short-run variations in the capacity utilization rate can be large in the forest industries, he does not include it as a possible channel of substitution (see op. cit. p. 18).

11. F(x) is said to be a *homothetic* function if there exists a continuous and positive monotone increasing transformation Φ (f) such that g(x) = Φ [f(x)] is homogeneous of degree one (see Takayama (1985) Chp. 1, Section F for a further elaboration of the concept). Intuitively, homothetic production and cost functions keep inputs' income and factor shares constant irrespective of changes in the scale of production. Thus, marginal substitutions between inputs do not depend on the level of production. On the other hand, the *nonhomotheticity* assumption implies that pure scale changes alter relative marginal products and thus affect factor proportions and relative shares independently of factor prices.

12. For other applications of the static translog cost approach in forest industry studies, see, for example, Stier (1980), Nautiyal & Singh (1985), and Martinello (1987). For a criticism of the translog approach, see Cardellichio (1986).

13. Berndt, E.R., Fuss, M.A. & Wawerman, L. 1977. Dynamic models of the industrial demand for energy. Electrical Power Research Institute, Research Reports EA-580, Paolo Alto, CA; above authors 1980. Dynamic adjustment models of industrial energy demand: empirical analysis for U.S. manufacturing, 1947—1974. Electr Power Res Inst Res Rep EA-1613, Paolo Alto, CA; Lucas, R. 1967. Optimal investment policy and the felxible accelarator. International Economic Review 8(1): 78—85; Treadway, A.B. 1971. The rational multivariate flexible accelator. Econometrica 39(5): 845—855; and Treadway, A.B. 1974. The globally optimal flexible accelator. Journal of Economic Theory 7: 17—39.

3. Theoretical model

31. Static long-run model

As was indicated above, the theoretical framework of the present study is based on neoclassical production theory and the application of duality theory. To be more specific, the model used in this study in based on the following assumptions. First, it is assumed that the representative firm in the pulp and paper industry operates under the technical constraint of a production function which relates the flow of gross output, Q_G, of the industrial sector to four inputs, capital (K), labour (L), energy (E), materials (M) and technical change (T).

$$Q_G = f(\mathrm{K,L,E,M;T}) \tag{3.1}$$

Duality theory allows the production technology to be represented either by a cost or profit function.[1] In the present study it is assumed that factor prices and output levels are exogenously determined and that the representative firm in the industry is minimizing costs. The cost minimization assumption is probably a close approximation to reality. In markets where the Finnish pulp industry sells at world prices, increased factor costs imply a reduction in the quantities that can be sold profitably. Thus, the success of the Finnish pulp industry to compete in world markets with, for example, Sweden, Canada and the United States is determined by its ability to produce at low costs. Consequently, in accordance with the majority of studies in the literature, the cost function approach is also used here. However, as was noted in Section 22. minimization of costs is equivalent to a problem of maximization of profits subject to a given output, both requiring the same regularity conditions and yielding the same optimal behaviour. The assumption of exogeneous input prices and the possible failure of the underlying data to be consistent with this assumption are considered in Sections 41. and 52. Given the above assumptions, the production technology can be represented by the following cost function.

$$\mathrm{C} = g\,(P_K, P_L, P_M, P_E, Q, T) \tag{3.2}$$

where C is the total cost of production, P_i, $i = K, L, M, E$ are factor prices and T is a time trend indicating technical change. The cost function is assumed to have the properties outlined in footnote 4 in Chapter 2. In order to make the cost function operational, it is necessary to specify a mathematical functional form for it. In Section 22. the different functional forms and the problems related to their empirical applications were discussed. It was noted that the new generation of FFFs (i.e., generalised McFadden, Fourier, and Minflex functions) are to be preferred on the account of their global properties. However, the trade-off associated with using these functions is that the number of estimated parameters increases and that nonlinear estimation methods must be used. Since in the present study the data consists of only 27 observations and the econometric program (Limdep) used for estimation does not provide the appropriate nonlinear estimation method, the translog form was chosen for the empirical application.[2]

The translog cost function used here takes the following form.

(3.3)

$$\begin{aligned} lnC = {} & \alpha_0 + \alpha_Q\, lnQ + \alpha_L lnP_L + \alpha_K lnP_K + \alpha_E lnP_E + \alpha_M lnP_M + \alpha_T T + \frac{1}{2}\alpha_{TT}T^2 \\ & + \frac{1}{2}\alpha_{QQ}(lnQ)^2 + \frac{1}{2}\alpha_{LL}(lnP_L)^2 + \alpha_{LK} lnP_L lnP_K + \alpha_{LE} lnP_L lnP_E + \alpha_{LM}\ln P_L lnP_M \\ & + \frac{1}{2}\alpha_{KK}(lnP_K)^2 + \alpha_{KE} lnP_K lnP_E + \alpha_{KM} lnP_K lnP_M + \frac{1}{2}\alpha_{EE}(lnP_E)^2 + \alpha_{EM} lnP_E lnP_M \\ & + \frac{1}{2}\alpha_{MM}(lnP_M)^2 + \alpha_{QL} lnQ lnP_L + \alpha_{QK} lnQ lnP_K + \alpha_{QE} lnQ lnP_E + \alpha_{QM} lnQ lnP_M \\ & + \alpha_{TQ} T lnQ + \alpha_{TL} T lnP_L + \alpha_{TK} T lnP_K + \alpha_{TE} T lnP_E + \alpha_{TM} T lnP_M \end{aligned}$$

In order to ensure that the underlying production function is well-behaved, the cost function must be homogeneous of the first degree in input prices. The requirement ensure that, for a given level of output and technical change, an equi-proportionate change in all factor prices results in a proportionate change in total production costs. This implies the following reationship among the parameters:

$$\begin{aligned} & \alpha_L + \alpha_K + \alpha_E + \alpha_M = 1 && \alpha_{TL} + \alpha_{TK} + \alpha_{TE} + \alpha_{TM} + = 0 \\ & \alpha_{LL} + \alpha_{LK} + \alpha_{LE} + \alpha_{LM} = 0 && \alpha_{QL} + \alpha_{QK} + \alpha_{QE} + \alpha_{QM} = 0 \\ & \alpha_{EE} + \alpha_{EL} + \alpha_{EK} + \alpha_{EM} = 0 && \\ & \alpha_{MM} + \alpha_{ML} + \alpha_{MK} + \alpha_{ME} = 0 && \end{aligned} \tag{3.4}$$

Without any further restrictions on the parameters, the cost function (3.3) allows for non-constant returns to scale, non-homotheticity and non-neutral technical change. The translog approximation is homothetic if it can be written as a separable function of output and factor prices, i.e., if $\alpha_{iQ} = 0$ for all $i = K, L, E, M$. Homotheticity implies that the cost minimizing input-mix is determined purely by input prices and technical change and is independent of the level of production. Further, a homothetic cost function is homogeneous if the elasticity of cost with respect to output is constant, i.e., if $\alpha_{QQ} = 0$. Given these restrictions, the degree of homogeneity of the cost function is determined by the coefficient α_Q. Consequently, if $\alpha_Q = 1$, the cost function is linearly homogeneous and the underlying technology is characterised by constant returns to scale. Finally, the bias of technical change is indicated by α_{iT}. Thus, even with constant factor prices, the cost minimizing input-mix can be altered by technical change. Technical change is said to be Hicks neutral if $\alpha_{iT} = 0$ for all i. The above restrictions can be tested using simple likelihood ratio tests, provided the estimated coefficients are normally distributed.

Although it is possible to analyse the structure of production by estimating the cost function alone, the number of parameters to be estimated is quite large and multicollinearity is likely to be a serious problem. Thus, in practice, it is common to base empirical studies not on the cost function alone, but in addition to the derived factor share (demand) equations, or merely on the letter equations.

Given differentiability, the factor share equations can be derived using Shephard's Lemma, i.e., $\partial C/\partial P_i = x_i$ where x_i is the cost minimizing demand for the ith input. Consequently, we get the following factor share equations:

$$S_i = \frac{\partial\, lnC}{\partial \ln P_i} = \frac{\partial\, C}{\partial\, P_i}\frac{P_i}{C} \tag{3.5}$$

$$\begin{aligned} S_L &= \alpha_L + \alpha_{LL}\ln P_L + \alpha_{LK}\ln P_K + \alpha_{LE} lnP_E + \alpha_{LM} lnP_M + \alpha_{QL} lnQ + \alpha_{TL}T \\ S_K &= \alpha_K + \alpha_{KL}\ln P_L + \alpha_{KK} lnP_K + \alpha_{KE}\ln P_E + \alpha_{KM} lnP_M + \alpha_{QK} lnQ + \alpha_{TK}T \\ S_E &= \alpha_E + \alpha_{EL} lnP_L + \alpha_{EK}\ln P_K + \alpha_{EE}\ln P_E + \alpha_{EM}\ln P_M + \alpha_{QE} lnQ + \alpha_{TE}T \\ S_M &= \alpha_M + \alpha_{ML} lnP_L + \alpha_{MK}\ln P_K + \alpha_{ME} lnP_E + \alpha_{MM}\ln P_M + \alpha_{QM} lnQ + \alpha_{TM}T \end{aligned} \tag{3.5'}$$

In order for the system of factor equations (3.5') to satisfy the adding up criterion ($\Sigma S_i = 1$) and the properties of neoclassiccal production theory, the parameter restrictions of (3.4) are required. In addition, the Slutsky symmetry condition ($\alpha_{ij} = \alpha_{ji}$) must hold.

The characterictics of the underlying production technology, in terms of price, substitution and technology elasticities, can be derived using the formulas presented in Section 22.

32. Dynamic short-run model

An essential prerequisite for econometric studies is that the theoretical model conforms to the data which it is meant to explain. In other words, the assumptions of the model should be consistent with the observations one has on the economic phenomena from which inferences about economic behaviour are be to drawn. The static cost minimization model above was derived from producer equilibrium under the assumption that production technology is fully optimized with respect to the output level and the prevailing input prices. Only if this condition holds in the empirical sample can the estimated parameters be interpreted as shifts from one equilibrium to another. In the above static model the data can be assumed to approximate observations of different long-run equilibria only under the condition that all inputs fully adjust to output and price changes within one time period, i.e., within one year. As indicated by the large literature on dynamic factor demand models, this instantaneous adjustment to price or output changes is hardly realistic (see, e.g., Prucha & Nadiri 1986).

In section 23., different approaches used in the literature for modelling short-run dynamics in empirical factor demand studies were discussed. In the present study dynamics of factor demand is modelled using error correction model. In this approach, dynamics of the factor demand is not modelled using economic theory as such. Although the static part of the model is derived strictly from neoclassical production theory, the dynamic part is based on "statistical-theory", i.e., we seek to characterise the process whereby the data were generated. Also, in contrast to many other empirical studies, it is not assumed that any of the factors are quasi-fixed, but rather each factor is allowed to adjust at its own rate. This approach to dynamics is similar to the approach adopted, for example, by Hendry, Pagan & Sargan (1984). In the context of surveying different dynamic specifications, they state that: "Although theories of intertemporal optimising behaviour by economic agents are continuing to develop, this aspect of the specification problem is not stressed below since, following several of the earlier surveys, we consider that as yet economic theory provides relatively little prior information about lag structures" (op. cit. p. 1025).

For the "statistical" approach used below, the concepts of integrated series, cointegration and error correction, discussed in Section 23. are of a central importance. Until recently, econometric theory and its applications have been largely based on the assumption that the underlying data processes are stationary, despite the manifest non-stationarity of many aggregate time series to which theory has been applied. It seems that many economic time series do change in mean and often in variance so that their first two moments are not constant (see Nelson & Plosser 1982). The consequences for the statistical properties of estimators and tests are profound as evidenced by the literature on "spurious regression", "integrated series" and cointegration (see Phillips 1986, Phillips & Durlauf 1986, Engle & Granger 1987). One significant implication of the non-stationarity is that the usual statistical properties of the first and second sample moments do not hold. Consequently, standard normal distributional theory is not valid for non-stationary, non-ergodic processes.[3]

Although in the past few years more and more studies have employed the cointergation approach in empirical applications, no studies appear to have been published on factor demand systems which use flexible functional form cost functions. However, a priori, it would seem likely that time series data on levels of output, factor prices, production costs and factor shares could be non-stationary. Thus, it would be of interest to see whether the above approach is applicable in the context of the present study.

In order to understand what is meant and implied by the cointegration approach, a brief discussion of the concepts involved is necessary. However, it is not the intention, nor indeed possible, to give an exhaustive account of the relevant literature here. The research on the properties of integrated and cointegrated processes is still advancing rapidly and new results are being obtained. This caveat should also be borne in mind when interpreting the results of the present study. However, detailed accounts of the results obtained so far are documented, for example, in Eagle & Granger (1987) and in Aoki (ed.) 1988 and Hendry (ed.) 1986.

The concept of intergated series was introduced in economics by Granger (in 1980). A series, X_t, is said to be integrated of order d (denoted $X_t \sim$ I (d)) if it is a series which has stationary representation after differencing d times.[4] The relationship of integrated series to cointegration may be formally stated as follows: the components of the vector X_t are said to be cointegrated of order d, b (denoted $X_t \sim$ I (d, b)) if:

i) all components of $X_t \sim$ I (d)

and

ii) there exists a vector a ($\neq 0$) such that

$Z_t = a'X_t \sim$ I(d—b), b > 0:

the vector a is then called the cointegration vector.

The intuitive idea behind the above definition is that if, in the long run, two or more series move closely together, even though the series themselves are non-stationary, a linear combination of them is stationary. In other words, the two series have both a common stochastic trend and, by subtracting out this trend, the difference between these variables is stationary. These series may be regarded as defining a long-run "equilibrium" relationship. However, it should be noted that term "equilibrium" in the cointegration literature has a rather different interpretation than in economic theory in general. In the cointegration literature all that is meant by equilibrium is that it is an observed relationship which has, on average, been maintained by a set of variables for a long period. Thus, equilibrium implies none of the usual theoretical implications of market clearing and it does not imply that the system is at rest.[5]

An important implication of the definition of cointegration is that if two variables are integrated at different orders then these series cannot possibly be cointegrated and form a long-run relationship between an I(0) and I(1) series, because the I(0) series would have a constant mean while the mean of the I(1) series would go to infinity and so the error in the regression between them would be expected to become infinitely large.

The relevance of all this to the present study follows from the link between cointegrated variables and the error correction models (ECM). The so-called Granger Representation Theorem (see Engle & Granger 1987) states that if a set of variables is cointegrated, then there exists a valid error correction representation of the data. More formally, if X_t is an N × 1 vector such that $X_t \sim$ I(1, 1) and a is the cointegration vector then the following general ECM may be derived where $Z_t = a'X_t$

$$(3.6) \quad A(L)\,(1-L)\,x_t = -\,q'Z_{t-1} + d\,(L)\,e_t$$

where A(L) is a finite order polynomial and d(L) is a finite order lag operator and e_t is the error term. The error correction mechanism can be thought of as a description of the stochastic process by which the economy eliminates or correts the equilibrium error (see footnote 5).

The practical implication of the Granger Representation Theorem for the present study is that it provides a theoretical basis for the ECM, and thus for the short run dynamics, for the factor demand model *provided* the variables in the cost function (3.3) and the cost share equations (3.5) are cointegrated.

Engle & Granger (1987) have proposed a two-stage procedure, according to which the error correction model can be estimated consistently for cointegrated variables. The method is simple and can be computed by OLS estimation. First, one runs the regression equation (i.e., the cointegrated regression) in which the variables are in the levels form (e.g., equations (3.3) and (3.5') in the present study). Thus, the equation does not include any dynamic behaviour and it can be interpreted as describing the long-run "equilibrium" relationship. The residual (error term) of the equation measures the amount by which the equation differs from the equilibrium relationship. If the levels of the underlying variables (their time series) are non-stationary, but the equation is cointegrated, the parameter estimates are unbiased and consistent. However, the conventional test statsitics do not follow their usual distributions and cannot be used (e.g., t values are not t-distributed). The statistical validity of the cointegration equation can be judged on the basis of its residual. A number of different tests have recently been developed to allow appropriate inference of the statistical properties of the equation (see Chapter 4).

In the second stage of the estimation procedure, the residual (lagged by one period) from the levels equation is used as an explanatory variable in a dynamic equation in which all the other variables are differences of the first stage equation variables. This residual incorporates the information from the long-run, i.e., the cointergration equation. Since the variables in the second stage are stationary, classical statistical inference can be used.

Although the actual estimation methods are discussed in detail in section 43, it is convenient to describe the Engle & Granger procedure and its properties here. In order to illustrate the procedure, consider the cost share equation (3.5'). In the first stage of the Engle & Granger procedure the following equations are estimated:

$$(3.7) \quad S_i = \alpha_i + \alpha_{ij}\,lnP_j + \alpha_{iQ}\,lnQ + \alpha_{iT}T + Z_{i,t}$$

$$i, j = K, L, E, M$$

where $Z_{i,t}$ are the error terms. If the underlying series are non-stationary and in addition they form a cointegration relationship, i.e., $Z_{i,t}$ are stationary, the OLS estimate will give consistent estimates of the parameters, although they will not have the standard distributions.

Before moving on to discuss the second stage of the Engle & Granger procedure, it should be noted that the inclusion of the time trend in equation (3.6) is somewhat problematic. Although it is common practice to have a linear time trend variable in factor demand models to take account of technical change, the variables included in the cointegration regression should, strictly speaking, be nondeterministic. The problem arises, because the nonstandard asymptotic (and finite sample) distribution of non-stationary variables can be sensitive to the inclusion of the deterministic time trend. However, since in some of the empirical equations the fulfillment of theoretical concavity restrictions was sensitive to the omission of the time trend variable, it was included in these equations (see Chapter 4). A possible solution to the problem would be to try to use a suitable stochastic variable to represent technical change. However, this may introduce further problems as regards interpreting the results. In the present study, a pragmatic approach has been applied by examining the sensitiveness of the cointegration tests to the inclusion of the time trend variable.

The residuals are retained from the levels equations for the purpose of the second stage estimation. i.e.,

$$(3.8)\quad Z_{i,t} = S_i - \alpha_i - \alpha_{ij}\, lnP_j - \alpha_{iQ}\, lnQ - \alpha_{iT} T$$

If the statistical tests indicate that $Z_{i,t}$ are stationary, the Granger Representation Theorem can be used to model the error correction process. Consequently, we move on to estimate the short-run dynamic error correction equations shown below:

$$(3.9)\quad \Delta S_i = \alpha_{ij}\, \Delta\, lnP_j + \alpha_{iQ}\, \Delta\, lnQ + \alpha_z Z_{i,t-1} + v_t$$

where Δ denotes the difference operator and v_t the error term. If $-1 < \alpha_z < 0$, the previous period error (in levels) is corrected, i.e., reduced. The absolute value of α_z indicates the speed of adjustment to long-run equilibrium. Thus, if $\alpha_z = 1$, the error is fully corrected.

The Engle & Granger two-step approach and, more generally, models with integrated processes have been shown to have some desirable properties for empirical applications. First, Stock (1987) has demonstrated that the Engle & Granger two-stage estimation method produces asymptotically "super consistent" estimates, i.e., the order of convergence of the OLS estimates to their true values is faster ($0(N^1)$) than in the usual case with stationary variables ($0(N^{0.5})$). The implication of this result is that cointegrated vectors calculated from moderate-sized samples could be expected to be very accurate. Further, Phillips & Durlauf (1986) have shown that simultaneity bias or serial correlation problems do not arise, at least asymptotically, in models which are formulated and estimated with integrated processes. In the words of Phillips & Durlauf, "...least squares regression is consistent in multivariate regression where the regressors are contemporaneously correlated with the errors and where both errors and regressors may be jointly determined by quite general time series process. The central requirement of the result is that the regressors follow an integrated process..." (op.cit., p. 482). This implies that, for example, exogeneity tests are not necessary for nonstationary variables. The importance of this result becomes even more pronounced due to the fact, that there does not currently appear to be any statistically valid way of making inferences about exogeneity in models with nonstationary variables. However, it should be stressed that the above results do not necessarily hold in small samples. The empirical results from the studies by Banerjee et al. (1986) and Stock (1988) have shown that although the estimators (in cointegration regressions) may converge quickly, for a given sample size, they may still be inaccurate. Also, in a cointegrated regression the possible correlation between the explanatory variables and the error term may cause a small-sample bias, but not inconsistency (see Stock 1988).

Finally, some cautionary remarks about the practical applications of the Engle & Granger cointegration approach should be made. First, if the model has more than two variables, there may not be a unique cointegration vector, but several "equilibrium" relationship linking N > 2 variables. According to Granger (1986), "this lack of uniqueness leads to some interpretational problems in the ECM, which are similar to the identification problems of the classical simultaneous equations models" (op.cit., p. 221).[6] Secondly, the test procedures for

cointegration do not have well-defined limiting distributions and as a result the testing is not a straightforward procedure. Moreover, there exists a number of different model variations and different methods of estimating and testing the cointergration relationship, all of which may give somewhat different results (see, e.g., the articles in Aoki (ed.) 1988 and Linden 1989).

The above weaknesses in the cointegration approach are not necessarily devastating. For example, Johansen (1988) has suggested a maximum likelihood (ML) estimation procedure which offers solutions for the first and second problems. That is, the Johansen procedure provides estimates of all the possible cointegration vectors which exist between a set of variables as well as test statistics for the number of cointegration vectors which have an exact limiting distribution. Hall (1989) has applied the Johansen procedure to a cointegrated system and compared the results to those he obtained by estimating the same relationship using the Engle & Granger two-step method, i.e. OLS (see Hall 1986). Hall (1989) concluded that, "The ML estimator has been shown to provide estimates of the cointegrating vector which conform well with those given by OLS. It is also clear that different versions of the OLS equations are not providing estimates of different cointegrating vectors and that the differences are due to the small sample bias of the OLS estimates which should disappear asymptotically" (op.cit., p. 218).

Footnotes

1. In fact, in addition to the dual cost and profit functions, the production technology could be described by a dual production function, which is a production analog of the indirect utility function in consumer theory. The indirect production function (IPF) is based on the firm's output maximization subject to a budget constraint on input costs. However, the only empirical application of the IPF within the context of a factor demand study of which we are aware is the recent study by Youn Kim, H. (1988), "Analyzing the Indirect Production Function for U.S. Manufacturing", Southern Economic Journal, October; 494—504.

2. For recent reviews of the theoretical aspects of the cost functions, see Diewert (1987) and Fuss (1987). The extensive empirical literature on estimating cost functions has been reviewed by Jorgenson (1986).

3. It should be noted that stationarity is not a sufficient condition for deriving consistent estimates from a finite realization of a series. In addition one needs a condition which restricts the "memory" of the process. One such condition can be derived from the so called "ergodic theorem", according to which the sample moments of a process converge asymptotically to the corresponding population moments. In general, ergodicity is usually assumed implicitly in the context of stationary series, since it is very difficult to prove ergodicity because the "population" of the series is usually infinite.

4. By *strict* (or strong) *stationarity* is meant a situation where the joint distribution of the stochastic process is independent of the time of observation. In other words, shifting the time origin has no effect on the joint distribution. Because of the difficulties of observing the exact distribution function, in practice the stationarity is usually defined in terms of *weak stationarity*.

Definition $\{x_t,\ t \varepsilon T\}$ is weakly stationary, if

a) $E(x_t) = E(x_{t+1}) = \mu_1$, constant, i.e., the mean of the series is constant.

b) $E[(x_t - \mu_x)^2] = \sigma_x^2 = E[(x_{t+1} - \mu_x)^2]$, i.e., the variance of the series is constant.

c) $cov(x_t,\ x_{t+k}) = E[(x_t - \mu_x)(x_{t+k} - \mu_x)] = cov(x_{t+1},\ x_{t+i+k})$, i.e., for any given lag, k, the autocovariance of the series depends only on the lag.

In some special cases the weak stationarity corresponds to strong stationarity. If the distribution of a series is completely described by its first and second moments (mean and variance) the weak stationarity implies strong stationarity. This is the case, for example, for the multivariate normal distribution.

5. In order to motivate the cointegration (and error correction) approach, Granger (1986) states that, "At the least sophisticated level of economic theory lies the belief that certain pairs of economic variables should not diverge from each other by too great an extent, at least in the long-run. Thus, such variables may drift apart in the short-run or according to seasonal factors, but if they continue to be too far apart in the long-run, the economic forces, such as a market mechanism or government intervention, will begin to bring them together again" (op.cit., p. 213). Thus, Granger is suggesting that we understand the long-run tendencies of economic variables better than the short-run ones, i.e., economic theory may be valid for describing long-run equilibrium, but random shocks knock the economy away from equilibrium after which it moves back only slowly. Although Granger does not explicitly

state why the adjustment is not instantaneous, one can think of a number of reasons, such as, sticky prices, costs of adjustment, delivery lags or "time-to-build" lags, long-term contracts etc.

6. In a case where there exists a unique cointegration vector, the absolute value of the error correction term (Z_t) can be interpreted as describing the distance that the system is away from the unique equilibrium. In a "multi-cointegration" vector case, the error term can be thought to describe the distance the system is from the "equilibrium sub-space". If we denote the number of cointegration vectors, or the "order of cointegration", by r, and the number of time series included in the model by N, then, for general N, r, the equilibrium sub-space will be a hyper-plane of dimensions N-r (see Granger (1986)).

4. Institutional environment, data and estimation methods

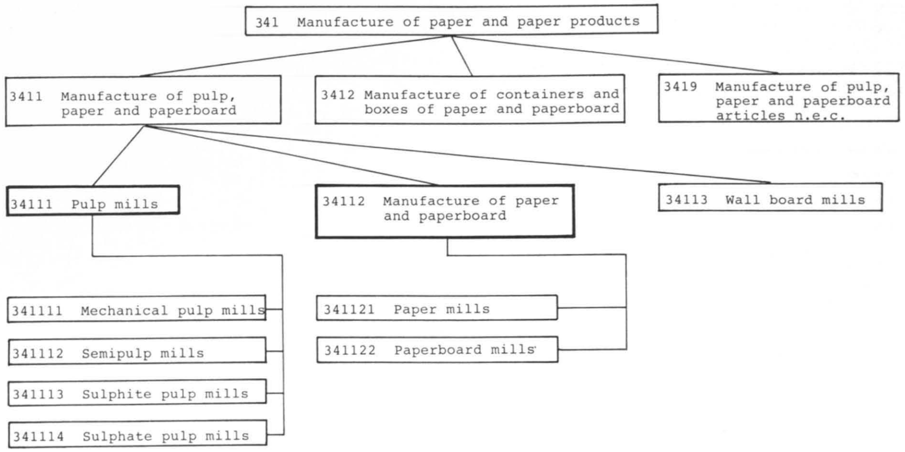
This chapter has three different sections. First, the characteristics of the Finnish pulp and paper industry are described. In particular, issues concerning the separation of the pulp and paper industry into two separate branches, the consumption of factor inputs in the production process and the determination of input prices are discussed. Second, the data series assumed to represent measurements of the theoretical variables of the models are described. Finally, the estimation methods used in the empirical part of the study are discussed.

41. Characteristics of the Finnish pulp and paper industry

The classification of the Finnish pulp and paper industry used in the present study is shown in Table 2. Because the principal source of the data in the study is the Industrial Statistics of the Central Statistical Office of Finland, our classification of the industry follows that source. The two branches that constitute the industries studied are shown by the heavily outlined boxes in Table 2, i.e., pulp mills (34111) and the manufacture of paper and paperboard (34112). Although these two branches are formed from heterogeneous sub-branches they are not analysed separately, because that would have caused major difficulties for data construction. Indeed, the data used here are already quite disaggregated compared to bulk of forest industry studies.

Whether the pulp and paper industry should be studied as an aggregate (i.e., as 341) or separated into its constituent sectors (i.e., 34111 and 34112) is ambiguous. In the literature, for example, Sherif (1983) and Törmä & Loukola (1986) use the aggregate approach. The problem arises because woodpulp is an intermediate product in the production of paper and much of it is directly consumed by paper-making operations integrated with pulp mills. On the other hand, some pulp is sold to other domestic producers or exported (see Table 2) and thus can be regarded as a separate product.[1] Consequently, the implicit assumption made, for example, by Sherif (1983) and Törmä & Loukola (1986), that pulp and paper products are perfect substitutes does not necessarily hold and the sectors may have to be studied separately. Indeed, because of the vertical integration of the pulp and paper industry, the data of the Industrial Statistics include a significant amount of double-counting at the aggregate industry level (341) as regards factor input (raw materials) and output figures. Consequently, the interpretation of results and the generalisations made on the basis of studying the aggregate pulp and paper industry are biased (for a further discussion of these problems, see Simula 1979, 1983 Ovaskainen 1986 and Katila 1988). Because these biases in aggregate data cannot be easily eliminated, the integrated industries have been separated into their constituent branches in the present study.

Table 2. Pulp and paper industry. Classification according to the Standard Industrial Classification (SIC) of the Central Statistical Office of Finland.



As can be seen from Table 2, a number of branches that come under the heading of manufacture of paper and paper products (341) are omitted from the present study. This is simply because their ommission helped to reduce the data construction problems considerably. In fact, the branches left out are only of minor importance for the pulp and paper industry as a whole. Of the gross value of production of the manufacture of paper and paper products (341) in 1986, the share of pulp mills (34111) was around 30 % and that of the manufacture of paper and paperboard (34112) around 54 %.[2]

One of the main characteristics of the Finnish pulp and paper industries is that they are heavily export-orientated. In Table 3, some of the key statistics of these industries are presented, including developments in the volume and value of exports. The figures reveal that in the paper industry the share of exports in the total volume of production has been very high and stable (around 80 %) throughout the whole period studied. For the pulp industry the corresponding figure declined from 45 % in 1960 to 19 % in 1986. This is due to the increase in the level of processing of pulp products in the domestic industry. That is, the pulp and paper industries have become more integrated and an increasing part of pulp production is used in the domestic paper industry.

All the empirical studies in Finland have assumed that the Finnish pulp and paper industries are price takers in input markets (Simula 1979, 1983, Tervo 1986, Törmä & Loukola 1986 and Kuuluvainen et al. 1988). However, this assumption is not unambigious and needs some explanation. Thus, a brief look at the determination of the different input prices is called for.

Starting with labour input, wages and salaries are largery determined as the outcome of collective bargaining between the trade unions and the employers' association of the pulp and paper industries. Although adjustments are frequently made and wage drift has exceeded negotiated increases in wage rates, a substantial part of the decision-

Table 3. Descriptive statistics of the pulp and paper industry.

	Pulp mills (34 111)				Paper and paperboard (34 112)			
	1960	1970	1986	Change % 1960/86	1960	1970	1986	Change % 1960/86
1 Number of mills		62	47			27	30	
2 Average size of mill (1000t/year) (5/1)		100	169			163	252	
3 Number of employees	16 274	16 347	8 971	-45	15 939	21 770	22 202	+39
4 Number of employees /5	4.6	2.6	1.1		8.1	5.0	2.9	
5 Production (1000 million tons)	3 515	6 222	7 928	+126	1 970	4 395	7 549	+283
6 Exports (1000 million tons) (% of 5)	1 595(45)	2 057(33)	1 479(19)	-7	1 610(82)	3 492(79)	6 163(82)	+282
7 Gross value of production, (GVP, million Fmk, 1949=100)	6 090	11 233	11 783	+93	5 245	11 133	21 227	+305
8 Value of exports (% of gross value of production, current prices)	3 358(55)	5 019(45)	3 094(39)	-8	1 938(37)	3 768(34)	17 812(84)	+819
9 Value added	1 565	3 647	1 570		1 448	3 532	6 846	
10 Value of raw materials and semifinished products	2 102	4 551	7 604		1 763	4 526	10 906	
11 Value of purchased electric power as % of GVP, current prices	5.9	3.8	8.4		4	2.9	4.5	
12 Consumption of electricity (1000 kWh) /5	649	743	922	+42	640	754	853	+33
13 Wages and salaries as % of GVP, current prices	10	8.5	5.3		10.5	11.4	7.2	
14 Consumption of roundwood (million m3)	16	28	33.5	+109				
15 Consumption of roundwood (1000 m3) /5	4.6	4.5	4.2					

* deflated by production price index (1949=1 0), million Fmk

making power on wages and salaries lies outside individual firms. The number of employees (salary and wage earners) and the share of wages and salaries in the gross value of production in the pulp and paper industries are given in Table 3. The number of employees needed to produce a given volume of output (in 1000 million tons) in the pulp industry fell from 4.6 in 1960 to 1.1 in 1986. The respective figures for the paper industry are 8.1 and 2.9. Thus, the labour-intensiveness of production has decreased significantly.

As regards capital input, it seems justified to assume that the price of capital is exogeneous to the pulp and paper industries for they have only limited possibilities to influence their financing costs.

The determination of the roundwood input price has been a source of lively debate (see, for example, Tervo 1986, Brännlund 1988 and Kuuluvainen et al. 1988). In considering this issue, it is useful to look at supply and demand factors in turn. Starting with the supply side, the share of roundwood from private nonindustrial forests in the total wood consumption of the forest industry varied around 70—77 % on average over the period examined. The remaining 23—30 % was supplied from state forests (8—16 %), companies' own forests (6—13 %) and roundwood imports (1—10 %) (these supply components have been examined in more detail in Tervo 1986). The share of imported wood in the total wood consumption of the *pulp industry* has shown the biggest change, steadily increasing from 1 % in 1960 to 14 % in 1986. The bulk of wood imports comes from the Soviet Union and the quantities are laid down in bilateral trade agreements between Finland and the Soviet Union. The increase in the share of wood imports has been accompanied by a decline in the shares of companies' own forests and state forests. In this study, we follow Kuuluvainen et al. (1988) in assuming that the supply of roundwood outside private forests does not singificantly affect the elasticity coefficients to be estimated (for a recent detailed study on the different factors determining the nonindustrial supply of roundwood, see Kuuluvainen 1989).

Turning to the demand side, we first note that in Finland most of the roundwood trade consists of stumpage sales, delivery sales having accounted for around one-third of total sales during the period studied. As regards delivery costs (i.e. harvesting and transport costs) which the industry has to pay before the wood can be used in production, they are assumed to be so stable in relation to stumpage prices that they can be ignored. This assumption was necessary since no readily available data exists on delivery prices for the whole period studied. It does not appear to be a critical assumption in the sense that stumpage costs constitute around 50 % of the total costs of wood input for the industry and the margins of adjustments in transport and harvesting costs are relatively small. Thus, stumpage prices are used as roundwood unit costs for the pulp industry.

In the literature, basically two reasons are put forward to explain why the stumpage price may differ from the competitive price (see, for example, Naskali 1986 and Kuuluvainen et al. 1988). First, pulpwood users are small in number and they (buyers) have acted in cooperation. Secondly, nationwide price recommendation agreements for pulpwood have been concluded for most felling seasons since the mid-1960's. However, as Kuuluvainen et al. (1988) point out, these factors do not necessarily hinder price competition in pulpwood markets. As regards the first claim, concentration in the market does not necessarily lead to monopsony (oligopsony) pricing, since the market structure is neither a sufficient nor a necessary condition for certain behaviour. On the other hand, despite price recommendation agreements there is reason to believe that price continues to be a real means of competition in the pulpwood trade. In support of this claim Kuuluvainen et al. (1988) refer to "price drift", i.e. the deviation of actual prices from recommended stumpage prices (see op. cit. p. 194).

In Table 3, the quantity of roundwood used in pulp production is given. Although the absolute quantity increased by 109 % from 1960 to 1986 (in million cubic metres), the quantity for a given volume of production has remained fairly stable.

When considering the price of the pulp input and the other raw material costs in the pulp industry, one has to take account of the fact that the pulp industry is to a large extent integrated with the paper industry. Thus, transfer prices have been used in the valuation of pulp output (input) in integrated units. These prices may diverge from market prices, thereby influencing the results. There appears to be no way of avoiding this problem in empirical work and it has to be assumed that input prices derived from value (and quantity) series collected from firms (by the Central Statistical Office) reflect true costs. Alternatively, it could be assumed that input prices are equal to export (imported) raw material prices.

Similarily, problems attach to constructing price (and quantity) indices of electricity in the pulp and paper industries. The pulp and paper industry branch is the single biggest consumer of electricity in the whole manufacturing industry. The cost of purchased energy in the industry in 1986 was 2280 million Fmk, of which the share of electricity was 57 %. The share of energy (eletricity) costs in total production costs was 7.1 % (3.5 %) in 1986 (see, EKONO 1988). It can be seen from Table 3, that the consumption of electricity for a given volume of production (in 1000 million tons) has increased by 42 % and 33 % in the pulp and paper industries, respectively, in the period studied. However, a significant amount of this electricity is generated as a by-product of industry output. For example, apart from mechnical pulp, the pulp industry uses its own waste materials e.g. waste wood, process heat and black and sulfite liquors, on a large scale to generate electricity. However, the quantity of purchased electric power outside integrated firms has increased steadily.

In summary, on the basis of the arguments outlined above, input prices in the pulp and paper industries are taken to be beyond the control of a single firm. This conclusion was reached by looking at the domestic market environment in Finland. Alternatively, we could have used the *factor price equalization theorem* to argue that in Finland, which is a small open economy engaged in free trade and sharing a similar production technology to other countries (Sweden), factor prices cannot diverge from international prices (except as regards transport costs) and thus are given to the domestic industry.[3] Obviously, whether the actual price series used in a specific empirical application are exogenous is an empirical question.

42. Data and variables

The empirical implementation of the models requires time series data on quantities, prices and cost shares for five factor inputs, namely, labour, capital, electricity, roundwood and pulp.

The *labour* input series are the quantity indexes of hours worked (1985 = 1) multiplied by the 1985 value of total labour costs. The price of labour was defined as total labour costs divided by hours worked, normalized to 1985 = 1. Total labour costs include wages plus social security charges.

The definition of *capital* itself and the construction of variables pertaining to capital present considerable problems. Basically, what is needed is data on the capital stock and the user cost of capital. Neither of these can be taken directly from published statistics. The data on the net capital stock in the National Accounts are constructed for the whole pulp and paper industry (341). Furthermore, the depreciation rate used to construct the series is not consistent with the one used to construct the user cost formula in the present study. Indeed, the depreciation rate used in the Industrial Statistics apparently underestimates the average service lives of capital buildings and equipment in the pulp and paper industry.

The available net capital stock series was constructed assuming that capital depreciates according to the Weibull distribution. Consistency with the assumption of the present model requires that the net capital stock series is constructed using the capital accumulation equation:

$$K_t = I_{t-1} + (1 - d) K_{t-1} \quad (4.1)$$

where K_t = capital stock at the beginning of period t

I_t = gross investment during period t

d = constant rate of capital depreciation

In order to calculate K_t, the constant exponential rate of depreciation has to be determined. This was accomplished using the procedure present in Kuh & Schmalense (1973). According to this procedure the depreciation rate is calculated from the equation:

$$(1\text{-}d)^L = X, \quad (4.2)$$

where L = average service lives of capital goods

X = value of capital goods as a percentage of their initial value at the end of their average service lives

In the present study, the series on gross fixed capital formation in the Industrial Statistics was used to construct the relative shares of the pulp industry (3411) and the paper industry (3412) in capital formation in the industry as a whole (341). Furthermore, it was assumed that the aggregate net capital stocks in the pulp and paper industries are a weighted average of equipment and machinery and building structures, with weights of 0.63 and 0.37, respectively. Finally, it was assumed that, of the initial value of equipment and machinery, 10 % is left after 32 years in the paper industry and after 25 years in the pulp industry. The corresponding figure for building structures was assumed to be 65 years for both industries. These figures for the service lives of capital goods are higher than those reported in the National Accounts. The figures used here should be more accurate, since they are based on detailed calculations by Simula (1979) rather than on the crude approximations of the Central Statistical Office. However, the figures should still be regarded with some caution.

These assumptions imply that the following depreciation rates apply for capital goods:

Equipment and machinery	Building structures
Paper d = 0.069	d = 0.035
Pulp d = 0.088	d = 0.035

Using these depreciation rates, the data on gross investment (i.e., gross fixed capital formation in 1985 prices) and the net capital stock figures for 1960 as a benchmark, the series for the stocks of structures and equipment were constructed according to equation (4.1).

The price of capital, or the user cost, was calculated on the basis of the standard formula (ignoring taxes and capital gains), i.e.:

$$P_k = q_i (r + d), \quad (4.3)$$

where P_k = user cost

q_i = implicit price index of investment, 1985=1

r = rate of return

The above user cost series is a rather crude one and more sophisticated series could be constructed (see, e.g., Koskenkylä 1985). However, it is not clear whether it is necessary, for example, to include a tax parameter in the user cost formula. In a number of studies, it has been argued that tax allowances which are left to firms' discretion within legal limits may lead to neutrality at the corporate tax level (see, e.g., the theoretical studies by Kanniainen (ed.) 1987 and Ylä-Liedenpohja 1983, and empirical evidence from Peisa & Pulli 1988). Also, empirical measurement of expected capital gain (i.e., inflation) is difficult, not least because of the problems related to expectations specification. There exist a number of different expectations hypotheses and it is ambigious which one should be used in the user cost formula (see e.g., Koskenkylä 1985). In the present study, the nominal Bank of Finland call money rate is used as a measure for rate of return. Although the pulp and paper industry firms borrow from commercial banks and not from the Bank of Finland, the call money rate reflects the marginal investment costs of the firms. Indeed, in Finland the forest industry is to a large extent owned by commercial banks.

The quantity of *roundwood* is a weighted average of pine, spruce and non-coniferous pulpwood and wood chips and particles. The weights are the cost shares of each of type of wood in total roundwood costs. The quantity of roundwood is measured as the total consumption of industrial wood (in million cubic metres with bark) while the price of roundwood is the weighted average of stumpage prices (Fmk/cubic metres) for the different types of wood. The roundwood input is measured as total roundwood consumed in million cubic metres multiplied by the 1985 price per cubic metre consumed in million marks.

The quantity series for *pulp* input consists of "own" and "purchased" pulp. The price index for pulp input was derived by dividing the value of pulp input used in production by the quantity of pulp (tons).

The construction of the price and quantity series for *electricity* caused considerable difficulties. The quatity series were constructed by subtracting from the series of total consumption of electricity in the industry the series for the electrity generated within the industry. However, the problem was that the series on own generation of electricity in the Industrial Statistics in consistent only up to 1981, after which the reported series is inconsistent. In order to construct the series for remaining years, data on idustrial electricity produced by counterpressure, for which approximately 95 % is generated by the pulp and paper industry, were used. The annual changes in this series were used to update the Industrial Statistics series up to 1986 (1981 as a base year).

Two different series were used for the price of electricity. This is because there is some ambiguity as to how one should measure the price accurately. The implicit price index series for electricity which can be derived from the Industrial Statistics may be biased, because different factories report the value of electricity used in various ways to the Central Statistical Office. Some base their calculations on the "market price" of electricity, i.e., the price at which electric power corporations sell electricity to factories, while some use an "opportunity cost" method of calculation. Consequently, in the present study, both the implicit price index and the IVO tariff index (obtained from the Electricity Pricing Department of the Imatran Voima (IVO) power corporation) were used. However, the preliminary results showed that if the IVO index was used, the cost share equations did not fulfil the theoretical concavity conditions for electricity. One reason for this result may be the fact that the IVO tariff index is biased for individual industries, since the price IVO charges varies according to the quantity of electricity purchased. Thus, for example, large users of electricity, such as the pulp and paper industry, are charged less than the smaller users. As a result of these difficulties, the implict price index derived from the Industrial Statistics was used as the price of electricity in both industries.

Total costs were defined as the sum of outlays on labour, capital, electricity and roundwood or pulp.

43. Estimation methods

The estimation of the static and dynamic factor demand models involves basically three different stages. First, the static factor demand equations (i.e., equations (3.7)) are estimated. Second, the stationarity or the order of integration of the underlying time series and the residuals of the factor demand equations are examined. Third, the dynamic factor demand equation system is estimated (3.9). Each of these stages is described in turn, below.

In Chapter 3, the cost function and the cost share equations of the factor demand model were derived. However, because of problems with the data, the inherent multicollinearity of the variables in the cost function and the difficulties of dynamic parametrisation of the cost function, only the factor share equations are estimated (i.e., equations (3.5)). Indeed, the fact that it is not necessary to estimate the cost function is one of the very reasons why the flexible functional forms have been popular. The substitution structure between factor inputs, the analysis of which is the primary objective of the present study, can be estimated without th cost function. The trade-off entailed in not estimating the cost function is that information on cost and scale elasticities and on total factor productivity cannot be obtained.

The cost share equations, which form a "system of seemingly unrelated equations" (SURE), are estimated as a system with parameter restrictions across the equations. The cost shares sum to unity at each observation and, consequently, the equation system is singular. This implies that the disturbance terms sum to zero across the equations and the contemporaneous disturbance covariance matrix is singular. The most common method of dealing with this problem is to delete one of these equations from the system and choose an estimation procedure which is invariant to which equation is delated. No information is lost, however, since the parameters for the deleted equation can be derived using the parameter restrictions. The estimation method chosen here was Zellner's iterative three-stage least square method (ZI3 SLS). In the program used (i.e., Limdep), initially the ordinary least squares (OLS) estimates are obtained for each equation and an estimate of the disturbance covariance matrix is computed from the OLS residuals. The Generalized Least Squares (GLS) estimate is then obtained by stacking the equations and applying the usual technique (see Pindyck & Rubinfeld 1981, pp. 164—168). The estimated disturbance covariance matrix obtained at the GLS step is used to re-enter the iteration and compute an update parameter vector. This process is continued until the log-likehood converges (at the sixth significant digit). The iterative Zellner estimates will converge to the full information maximum likelihood estimates.

Once the system of static factor share equations has been estimated, the order of integration of the underlying time series and the stationarity of the residuals are examined. This is necessary for the valid estimation of the dynamic error correction equations and in order to be able to draw valid inferences from the statistical tests. The traditional approach to examining the degree of integration of a time series is to rely on an informal inspection of the autocorrelation function (correlogram). Then, if the correlogram quickly approaches zero and then remains close to zero, the time series would be judged to be stationary. Although this method can give a rough approximation, it is obviously not very precise. However, recent research on integrated series has produced a number of different statistical tests which can be used to determine the degree of integration of a variable and to test whether a cointegration relationship exists. In the present study, the tests which have been most frequently used in the literature are applied. These tests are described below.

The Cointegrated Regression Durbin-Watson (CRDW) test:

Once the error term, Z_t, has been estimated, the null hypothesis that Z_t is non-stationary can be tested by testing whether $\rho = 1$ in the equation: $\varepsilon_t = \rho\varepsilon_{t-1} + v_t$, ($v_t \sim$ NID). Since the Durbin-Watson statistic is approximately $DW \approx 2(1-\rho)$, the H_0 is rejected if DW is significantly different from 0. This test statistic is called the CRDW test. The CRDW test is applicable only in random walk cases and cannot be used for higher order autoregressive processes. Critical values for the CRDW test have been simulated by Sargan & Bhargava (1983), Bhargava (1986), Engle & Yoo (1987) and Engle & Granger (1987).

The Dickey-Fuller (DF) test:

Run a regression $\Delta Z_t = \theta_1 Z_{t-1} + \varepsilon_t$. Then under the null hypothesis (H_0) that $\rho = 1$, $\theta_1 = 0$, if $\rho < 1$, $\theta_1 < 0$. The test is performed to test whether ρ_1 is significantly less than zero. The t statistic for θ_1 is the DF statistic. The DF test assumes the first order autoregressive process to be the correct model specification. Critical values for the DF test have been simulated by Fuller (1976), Dickey & Fuller (1981), Engle & Yoo (1987) and Engle & Granger (1987).

The Augmented Dickey-Fuller (ADF) test:

Run the regression

$$\Delta Z = \theta_1 Z_{t-1} + \sum_{i=1}^{N} \gamma_i \Delta Z_{t-i} + \varepsilon_t.$$

Then again under the null (H_0) that

$\rho = 1$, $\theta_1 = 0$ and if $\rho < 1$, $\theta_1 < 0$. The t test is used to test whether θ_1 is signifiticantly less than zero, the t statistics for θ_1 being the ADF statistic. The ADF test allows more dynamics than the DF test. However, it is over-parameterized in the first order autoregressive case. For critical values of the ADF test, see op. cit.

If the factor demand equations are cointegrated, the second stage of the Granger and Engle two-stage procedure can be estimated. Basically, the second stage dynamic factor demand system is estimated using the ZI3SLS method described above. However, the symmetry restrictions imposed on the parameters of the static model are not imposed on the dynamic model. In the short-run, it is not assumed that agents are in equilibrium and therefore there seems no reason why short-run behaviour should satisfy any such restrictions. Thus, during the adjustment process the effect of a change in one of the input prices on each share is allowed to be asymmetrical. However, since the estimated factor shares in total cost will always sum to unity, the adding up restrictions are imposed in the short-run. It may be noted that a similar approach has been applied in dynamic factor demand studies by Anderson & Blundell (1982) and Holly & Smith (1989).

The problem of singularity of the dynamic system has to be dealt with. Analogous to the static model, the dynamic equation system cannot be estimated directly as it has the property that any of the factor share equations can be expressed as a linear combination of the other equations. In the static model, one equation could be deleted and the parameters of the redundant equation recovered using the parameter restrictions. However, in the short-run model the adding up restrictions can only be used to recover the factor price parameters, not the error correction parameters. There are no tractable restrictions that can be imposed on the adjustment terms. A pragmatic approach to this problem was chosen and four different dynamic systems were estimated, each time one of the factor demand equations being deleted. The results from the equations in which the $\bar{R}^2$ statistics are the highest are presented. Although this approach is not fully satisfactory, it may be noted that the results are not, in general, very sensitive to which equation is deleted. Furthermore, the system estimation results are compared to results obtained by equation-by-equation ordinary least squares estimations.

Finally, it should be noted that in the case of cointegrated regression the time series follow integrated process and the bias due to the potential non-exogeneity of the explanatory variables vanishes asymptotically ("the Phillips & Durlauf result"). In the dynamic, short-run equation system the variables are stationary and this result does not hold. However, it is the "long-run" exogeneity of the *levels* of the prices that matters, because it is on them that producers normally base their optimizing behaviour in economic theory.

Footnotes

1. One way to try solve the problem would be to consider only exported pulp as the net output of the industry. However, when studying the factor substitution possibilities, scale economies and tehcnological progress of the woodpulp industry, consideration of total woodpulp produced by the industry seems to be more meaningful. In addition, it should be mentioned that, at least in the case of Finland, a significant amount of the woodpulp exported goes to Finnish paper mills located abroad.

2. Of the gross value of production in the manufacture of paper and paper products (341) in 1986, the share of wall board mills (34113) was 0.5 %, the share of the manufacture of containers and boxes of paper and paperboard (3412) was 7.6 % and the share the manufacture of pulp, paper and paperboard articles n.e.c. (3419) was 7.2 %.

3. The factor price equalization theorem was first stated by P.A., Samuelson (1948), "International Trade and the Equalization of Factor Prices", Economic Journal 58, 163—84. A recent interesting synthesis and extension of some of the results obtained in the literature on factor price equalization, is the study by P.J. Neary (1985), "International Factor Mobility, Minimum Wage Rates, and Factor-Price Equalization: A Synthesis", Quarterly Journal of Economics, vol. C, August; 551—70. Neary shows that even in some extremely general models of small trading economies the property of international factor price equalization obtains.

5. Econometric model and estimation results

This chapter presents the econometric model and estimation results for the pulp and paper industries. First, the econometric model is specified, and then the estimation and elasticity results are presented for each of the idustries.

51. Specification of the econometric model

As was noted above, only the cost share equations (3.5') are estimated. Furthermore, it is assumed that the technology is of the constant returns to scale type, i.e., $\alpha_Q = 1$ (a similar approach has been applied, e.g., by Berndt & Wood 1975). Constant returns to scale was assumed because of the difficulties of constructing a series for output which would have been consistent with the factor inputs used in the share equations. The variables used to represent material input in the empirical models do not correspond to the itermediate input series of the Industrial Statistics and consequently the output series in the models of the study are not identical to the gross output series of the Industrial Statistics.

The equation system (3.5'), subject to the restrictions in (3.4), constitutes the estimable equations of the translog long-run factor share functions. For empirical implementation the equations have to be embedded within a stochastic framework. To do this, it is assumed that the factor share equations are stochastic on account of errors in optimization. Thus, an additive disturbance term, ε_i, $i = K, L, M, E$, is appended to each of the equations, and the resulting disturbance vector is assumed to be independently and identically multivariate normally distributed.

$$
\begin{aligned}
(5.1)\quad S_L &= \alpha_L + \alpha_{LL} lnP_L + \alpha_{LK}\ln P_K + \alpha_{LE} lnP_E + \alpha_{LM}\ln P_M + \alpha_{TL}T + \varepsilon_L \\
S_K &= \alpha_K + \alpha_{KL}\ln P_L + \alpha_{KK}\ln P_K + \alpha_{KE}\ln P_E + \alpha_{KM}\ln P_M + \alpha_{TK}T + \varepsilon_K \\
S_E &= \alpha_E + \alpha_{EL}\ln P_L + \alpha_{EK}\ln P_K + \alpha_{EE}\ln P_E + \alpha_{EM}\ln P_M + \alpha_{TE}T + \varepsilon_E \\
S_M &= \alpha_M + \alpha_{ML}\ln P_L + \alpha_{MK}\ln P_K + \alpha_{ME}\ln P_E + \alpha_{MM}\ln P_M + \alpha_{TM}T + \varepsilon_M
\end{aligned}
$$

where S_L, S_K, S_E and S_M are cost shares of labour, capital, electricity and materials, respectively, in the total cost of producing the output; lnP_L, lnP_K, lnP_E and lnP_M are the logarithmic prices of labour, capital, electricity and materials, respectively, and T is a time trend denoting technical change. The materials input corresponds to roundwood input in the pulp industry model and to pulp input in the paper industry model. The roundwood and pulp inputs were chosen as a separate inputs because of their importance in pulp production and paper production, respectively. Furthermore, they were analysed separately form the other materials in order to derive own -and cross-price elasticities for wood and pulp inputs in Finland, for which no calculations exist in the literature. It should also be noted that the roundwood and pulp inputs are the major cost items in the materials aggregate. Also, the electricity input was analysed separately from the other intermediate inputs and form the other forms of energy. This was bacause the consumption of electricity in the (mechanical) pulp industry and the paper industry has increased significantly over the period investigated (see Table 3, Chapter 4) and it is overwhelmingly the most important of the energy forms in these industries. Furthermore, empirical evidence from factor demand studies has indicated that different energy components (e.g., electricity and fuels) react in different ways to changes in the prices of other factor inputs (see, e.g., Donnelly 1987 and Törmä 1987). The series used for electricity corresponds only to the quantity of *purchased* electricity used in production, thus the difficulties of measuring the appropriate electricity input is to some extent avoided (see the discussion in Section 42.). This separate analysis of roundwood and electricity inputs is also interesting in view of the well-known concerns that forest industry representatives have expressed about the prices and supplies of these inputs, on the one hand, and policy planners' concerns about the conservation of forests and future energy policy, on the other hand. Finally, the modelling of the factor shares according to the above equations assumes implicitly that the L, K, E and M inputs are weakly separable as a group from the residual materials input.

52. The pulp industry

Results of the long-run model

Since the cost shares in (51.) sum to unity, only three of the four equations are linearly independent. Therefore the labour share equation was arbitrarily dropped from the estimation procedure. The Zellner iterative three-stage least square estimations, with the theoretical restrictions imposed, produced the following results:

$$
\begin{array}{lllllll}
(5.2)\ S_K = & -0.051 & -0.474 lnP_L & +0.045 lnP_K & +0.345 lnP_E & +0.085 lnP_M & -0.005T \\
 & (-1.79) & (-10.90) & (1.00) & (8.07) & (1.98) & (-3.90) \\
 & & & & & & \bar{R}^2 = 0.97 \\
S_E = & 0.441 & +0.277 lnP_L & +0.345 lnP_K & -0.381 lnP_E & -0.241 lnP_M & -0.001T \\
 & (13.40) & (4.59) & (8.07) & (-5.31) & (-5.72) & (5.91) \\
 & & & & & & \bar{R}^2 = 0.87 \\
S_M = & 0.35 & +0.203 lnP_L & +0.085 lnP_K & -0.241 lnP_E & -0.046 lnP_M & -0.005T \\
 & (10.80) & (3.29) & (1.98) & (-5.72) & (-0.70) & (-3.90) \\
 & & & & & & \bar{R}^2 = 0.45
\end{array}
$$

The actual and fitted values of the equations are shown in the Appendix C1.

Before inferences about the above parameter estimates and the test statistics can be drawn, the properties of the underlying time series of the variables have to be known. In particular, it is necessary to determine the order of integration of the series and to examine whether the variables possibly form a cointegrated realtionship. First, the autocorrelation functions, shown in Table 4, were computed for each of the series.

Examination of the above results for the autocorrelation functions appears to indicate that all the levels terms of the variables are non-stationary. The first autocorrelation coefficient is rather high for majority of the series

Table 4. Autocorrelation functions of the series.

Series	lags:	1	2	3	4	5
$\ln P_L$		0.904	0.803	0.698	0.593	0.488
ΔlnP_L		0.309	0.212	-0.045	-0.026	-0.007
lnP_K		0.912	0.811	0.707	0.601	0.488
ΔlnP_K		0.565	0.322	0.215	0.044	0.074
$\ln P_E$		0.937	0.843	0.749	0.645	0.526
$\Delta\ln P_E$		0.080	0.082	0.231	-0.081	0.217
lnP_M		0.937	0.843	0.749	0.645	0.526
ΔlnP_M		0.080	0.082	0.231	-0.081	0.217
S_K		0.879	0.755	0.667	0.577	0.476
ΔS_K		-0.119	-0.083	-0.222	-0.071	0.099
S_E		0.755	0.601	0.363	0.210	0.140
ΔS_E		-0.048	0.003	-0.109	-0.058	0.209
S_M		0.654	0.322	0.203	0.133	0.156
ΔS_M		0.069	-0.322	-0.074	-0.058	0.260

Table 5. Sargan-Bhargava CRDW test.

Series	CRDW	constant "t"	trend "t"
lnP_L	0.30	17.26	51.73
ΔlnP_L	1.34	5.06	0.30
lnP_K	0.17	-1.63	21.87
ΔlnP_K	1.02	0.80	2.55
lnP_E	0.36	25.04	16.32
ΔlnP_E	1.60	0.36	0.81
lnP_M	0.70	18.27	14.81
ΔlnP_M	1.80	1.10	-0.13
S_K	0.85	10.61	18.26
ΔS_K	2.25	0.48	0.65
S_E	0.40	25.51	3.30
ΔS_E	2.23	-1.28	1.83
S_M	0.74	36.78	-1.88
ΔS_M	1.80	1.10	-0.13

Table 6. DF -and ADF -tests ("t" -values).

Series	DF	ADF	constant	trend
$\ln P_{L-1}$	-1.60		3.23	1.63
ΔlnP_{L-1}	-3.36		2.64	-0.13
lnP_{K-1}	-2.38		0.03	3.00
ΔlnP_{K-1}	-2.52		0.85	0.73
lnP_{E-1}	-1.46		1.64	1.44
ΔlnP_{E-1}	-3.80	-3.00	1.17	0.01
lnP_{M-1}	-2.28		2.52	2.12
ΔlnP_{M-1}	-4.53	-3.53	0.45	0.31
S_{K-1}	-2.74		2.65	2.83
ΔS_{K-1}	-5.54	-3.57	0.83	0.36
S_{E-1}	-1.47		1.19	2.35
ΔS_{E-1}	-5.56	-3.87	-1.75	2.28
S_{M-1}	-2.45		2.46	-1.09
ΔS_{M-1}	-4.87	-4.76	-0.47	0.50

and autocorrelation decreases slowly with increases in lags. Although the values of the autocorrelation functions of S_E and S_M series with one lag are rather low, the graphs of the series indicate that they are not stationary (see Appendix). However, the autocorrelation functions for the differenced variables, denoted by Δ, appears to be close to zero for all the variables, except for capital (ΔlnP_K) and labour (ΔlnP_L). Thus, inspection of the autocorrelation functions suggests that differencing the series removes the non-stationary of all the series, capital and labour being doubtful cases.

In order to obtain more rigorous evidence about the stochastic properties of the series, the CRDW and DF tests, shown below, were used. The augmented Dickey-Fuller test was not used, since inspection of the results of the regression of each of the levels series on their respective four lags indicated that all the series follow an AR(1) process (see Appendix for the regression results). The CRDW and DF tests were computed both with and without the drift and trend terms. The results concerning the stationarity of the series were similar in both cases. The results from the latter computations are given in Tables 5—6.

The critical value of the CRDW test for 25 observations at the 5 % significance level and with the trend included is 1.21 (see Bhargava 1986). The critical values for the DF test for 25 observations at the 5 % and 10 % significance levels and the drift and the trend included are —3.6 and —3.24, respectively (see Fuller 1976).

The CRDW test results reported in Table 5 indicate that all the series, except lnP_K, are I(1) processes. The t values of the levels series are very high because the error terms of the series are strongly autocorrelated. The DF test results in Table 6 are in line with the CRDW test results. According to the DF test, the first differences of all the series, except the ΔlnP_K and $\Delta\ln P_L$ series, are stationary. The $\Delta\ln P_L$ series can be regarded as being a I(1) process at the 10 % significance level. In fact, the doubtful cases of $\Delta\ln P_K$ and ΔlnP_L were also the series which had the highest autocorrelation functions in Table 4. In summary, the results imply that the capital and (less strongly) the labour series are likely to follow a higher order process than I(1), all the other series being clearly I(1). Finally, a word of caution about the tests should be made. Recently, Schwert (1987) has noted in the context of testing the stationary of number of USA macro series that DF and ADF tests may be biased if the series include significant moving average (MA) terms.

Further examination of the stochastic processes of the capital and labour series was done by computing the autocorrelation functions (shown below) for the second differences of the lnP_K and lnP_L. These results indicate that these series might follow the I(2) process.

Autocorrelation functions

Series	lag	1	2	3	4	5
$\Delta\Delta lnP_K$		−0.199	−0.152	0.033	−0.175	0.099
$\Delta\Delta lnP_L$		−0.445	0.152	−0.214	0.003	−0.009

In principle, the condition for the cointegration relation to be valid is that tha variables should be integrated of the same order. However, it is possible to have a valid cointegration relationship wiht a mixture of different order series if the higher order series are cointegrated with the order of the low order series (see Hall & Henry 1988). Thus, if the lnP_K and lnP_L series are both I(2) series, but there exists a cointegration vector between them which is I(1) the combination of these series and all the I(1) series can form a valid cointegration relationship.

Consequently, cointegration tests were computed in order to examine whether the differences of the capital and labour series are contegrated by regressing the variables against each other in both directions, i.e., ΔlnP_K on $\Delta\ln P_L$, and ΔlnP_L on ΔlnP_K. The CRDW and DF test statistics for the first regression equation were 1.55 and −4.02, respectively; and for the second equation 1.9 and −3.81, respectively. Comparing these values to their critical values (−3.67 for DF and 0.78 for CRDW, Engle & Yoo 1987), shows that the linear combination of the differenced series is stationary. It is therefore possible that all the variables in the above factor demand model could form a cointegration set.

On the basis of the above results, the following inferences can be made concerning the statistical properties of the cost share equations (5.2): First, the t values and R^2 statistics given are not valid, since they do not possess their conventional properties, when the data generating process is nonstationary. In particular, the t values are not normally distributied and the R^2 has nondegenerate distribution (see Phillips 1986 and Phillips & Durlauf 1986). In general, all tests based on normal distribution are subject to bias. Consequently, it is not valid to use, for example, the standard likelihood ratio tests for testing the theoretical restricitions, or compute confidence intervals for the parameters of the equations. However, if the variables in each of these cost share equations form a cointegrated relationship, the OLS parameter estimates are consistent although they do not have the usual normal asymptotic distributions. Furthermore, *if* the "super consistency" result holds in the present sample, the parameters converge to their true values faster than would be the case with stationary series. Also, the potential correlation between the explanatory variables and error term (e.g., on account of non-exogeneous or omitted variables) vanishes asymptotically (see Chapter 3). In fact, if the dependent and independent variables are cointegrated, then, despite invalidly taking lnP_i as *weakly exogeneous* (in the sense of the Engle et al 1983), no bias results in the long-run solution (see Hendry & Neale 1988).[1] Finally, it is possible to proceed to estimate consistently and efficiently the error correction form of the equations, using the Granger-Engle two stage method.

To establish whether the equations are cointegrated, one can use basically the above integration tests developed for the time series to test whether the error term (residual) of each of the cost share equations is stationary. However, it is not valid to use the same critical values for the residuals as for the single series directly, because the distributions of the residuals are dependent on the parametric representation of the model. In the literature, different critical values for different model specifications have been simulated, i.e., for a different number of parameters (see, for example, Engle & Granger 1987 and Engle & Yoo 1987).

The autocorrelation functions (Table 7) and the CRDW and DF tests (Table 8) are shown for the residuals of the three estimated cost share equations and for the omitted labour share equation. The residual for the labour share equation was computed using the singularity property of the factor share equation system. The ADF test was computed only for the capital share residual, since examination of the autoregressive processes of the residuals indicated that only the residual of the capital share equation has significant higher-order process, namely, the AR(3) term was significant (see the Appendix for the results). The graphs of the residuals are also presented, below.

The critical values of the CRDW, DF and ADF tests at the 5 % significance level, with 50 observations, two variables and no trend, are 0.78, —3.67 and —3.29 (2.90 at the 10 % level), according to the simulation results of Engle & Yoo (1987). For the sake of comparison, the corresponding values simulated by Engle & Granger (1987) for the first order autoregressive process, with 100 observations, are 0.386 (CRDW) and —3.37 (DF) (—3.03 at the 10 % level), and 3.17 for the ADF test.

Table 7. Autocorrelation functions of the residuals.

Residual	lag:	1	2	3	4	5
ε_K		0.329	-0.021	-0.342	-0.247	-0.195
ε_L		0.480	0.216	0.060	-0.100	-0.040
ε_E		0.460	0.216	-0.052	-0.249	-0.319
ε_M		0.455	0.011	-0.069	-0.083	0.033

Table 8. Cointegration tests.

Residual	CRDW	DF	ADF
ε_K	1.28	-3.47	-3.18
ε_L	0.90	-2.57	
ε_E	1.03	-3.12	
ε_M	1.02	-3.06	

The above results obtained from the autocorrelation functions and the CRDW test indicate that the residuals in each factor share equation may be (mean) stationary and, consequently, that the equations may be cointegrated. The autocorrelations with one lag are all under 0.5 and they decline rapidly as the lag increases. The CRDW statistics for the residuals show that they are above their critical values.

The Figures 1—4 show that the residuals have a mean close to zero and that there is a tendency for the residuals to return to the mean, so that they fluctuate around the mean. These are typical charasteristics of a stationary series. However, it may be noted that the residuals indicate that the model fails to some extent during the post-energy-crisis recession (in the latter half of the 1970's). This can also be seen from the comparisons of the actual and fitted values of the factor shares (see the Appendix). Including a dummy variable to take account of the "energy crises" might have given a better fit for these years.

In contrast, the DF test (and the ADF test) does not *unanimously* support stationarity at the 5 % level. If we use the Engle & Yoo (1987) critical values, none of the residuals of the cost share equations are stationary at the 5 % level. However, Engle and Yoo state that their critical values might be too large for small samples. Moreover, Linden (1989) has indicated that these values may too often favour the non-stationarity hypothesis. Consequently, if instead the Engle & Granger (1987) critical values for the DF test are used, all the residuals, except the residual for the labour share equation, are stationary at the 10 % level, and the residual of the capital share equation is also stationary at the 5 % level.

Because the CRDW and DF test results are not wholly consistent, i.e., the CRDW test indicated that all the residuals are stationary, while the DF test rejected stationarity for the labour share equation even at the 10 % level, it is of interest to note that a recent study by Durlauf & Phillips (1988) showed that the CRDW test is a very powerful statistic for testing unit roots (non-stationarity).2 On the whole, the evidence seems to favour accepting the hypothesis that the cost share equations are cointegrated. However, it should be remembered, that the critical values of the CRDW, DF and ADF tests have been simulated (by Monte Carlo) for single equation OLS estimations, while the cost share equations were estimated above as a system. The more robust procedure would, of course, be to simulate the values for the present study, but this approach was not chosen due to the computational difficulties.

Finally, in order to examine the sensitiveness of the cointegration tests to the inclusion of the linear time trend, the factor share equation system without the time trend was estimated. The results indicated that when the simulated values for the CRDW test form the Engle & Granger (1987) study were used, all the equations, except the S_E equation, were cointegrated at the 5 % significance level. By contrast, the DF test indicated that the null hypothesis of a significant unit root for any of the factor share equations could not be rejected. However, it should be noted that the results obtained from estimating the factor share system without the time trend *and* without the homogeneity and symmetry restrictions showed that alla the factor share equations were cointegrated at the 5 % level according to both the CRDW and DF tests (and on the basis of both the Engle & Granger 1987 and Engle & Yoo 1987 critical values). Thus, it appears that the cointegration test results are more sensitive to the theoretical restrictions than to the incluson of the time trend.

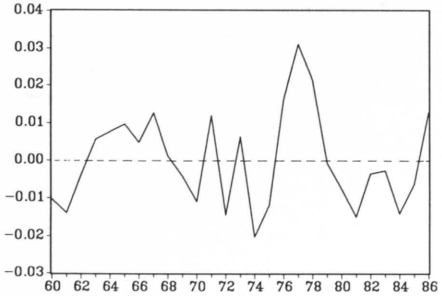


Figure 1. Capital cost share.

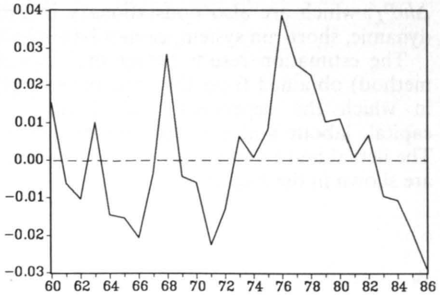


Figure 2. Labour cost share.

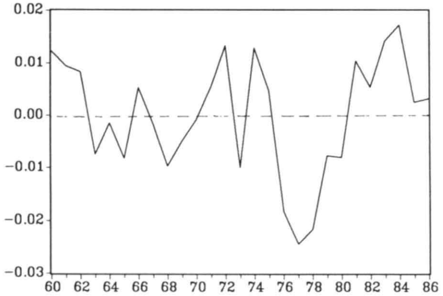


Figure 3. Electricity cost share.

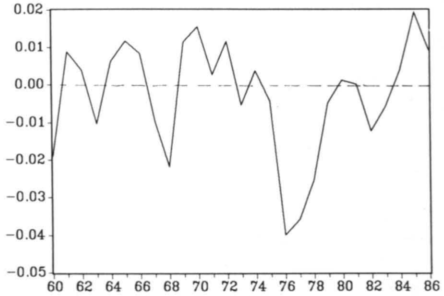


Figure 4. Roundwood cost share.

Results of the dynamic model

Having tentatively accepted the cointegration relationship between the variables of the share equations, the second stage of the Granger and Engle two-stage procedure can be estimated. If Z_K, Z_E, and Z_M are defined to be the derived residuals from equations (5.2) and Z_L is the residual for the labour share equation (derived from the singularity of the disturbances in the equation system), these residuals may then be included in a error correction model. The symmetry restrictions on the parameters used in the estimation of the static model were not imposed on the dynamic model.

Finally, it was noted above that in the case of a cointegrated regression the time series follow an integrated process and the bias due to the potential non-exogeneity of the explanatory variables vanishes asymptotically. Furthermore, in the present case, the exogeneity of the price series ΔlnP_K and

ΔlnP_L, which are also nonstationary in the dynamic, short-run system, cannot be tested.

The estimation results (using the Zellner method) obtained from the dynamic system in which the dependent cost shares are capital, labour and eletricity are presented. The actual and fitted values of the equations are shown in the Appendix.

(5.3)

$$\Delta S_K = -0.128\Delta lnP_L + 0.253\Delta lnP_K - 0.082\Delta lnP_E - 0.043\Delta lnP_M - 0.677Z_{K,t-1}$$

(-1.20) (2.54) (-1.04) (-0.85) (-4.18)

DW = 1.92 h = 0.36 $\bar{R}^2 = 0.60$

$$\Delta S_E = 0.131\Delta lnP_L + 0.137\Delta lnP_K - 0.139\Delta lnP_E - 0.128\Delta \ln P_M - 0.547Z_{E,t-1}$$

(1.50) (1.68) (-2.16) (-3.30) (-4.45)

DW = 1.54 h = 1.41 $\bar{R}^2 = 0.63$

$$\Delta S_L = -0.155\Delta lnP_L - 0.215\Delta \ln P_K + 0.335\Delta lnP_E - 0.035\Delta lnP_M - 0.531Z_{L,t-1}$$

(-1.38) (-2.07) (4.10) (-0.70) (-4.38)

DW = 1.13 h = 2.82 $\bar{R}^2 = 0.40$

The results, shown below, for the roundwood cost share equation were obtained from the system in which capital and electricity formed the other factor share equations.

$$\Delta S_M = 0.189\Delta lnP_L - 0.239\Delta \ln P_K - 0.071\Delta \ln P_E + 0.122\Delta lnP_M - 0.602Z_{M,t-1}$$

(1.82) (-2.51) (-0.94) (2.62) (-5.40)

DW = 1.00 h = 3.1 $\bar{R}^2 = 0.66$

The residuals of the dynamic cost share equations are shown in Figures 5—8.

In the estimated dynamic factor share equations, all the t values of the parameters, except ΔlnP_M and ΔlnP_E, have their usual interpretations since the series are stationary. The reported t values of the $\Delta \ln P_L$ and ΔlnP_K parameters should be interpreted with caution, since the series are non-stationary. In general, interpreting the absolute values of the differenced price terms is difficult. The theoretical conditions of the static model do not hold in the short-run model and symmetry restrictions can be violated. Consequently, elasticities calculated from short-run factor share equations without parameter constrains would not have the familiar interpretations. However, the primary interest in the short-run model is in the error correction terms. The validity of the error correction specification depends on the significance of these parameters. The results show that in all the short-run cost share equations the error correction term, Z_{i-1}, is highly significant and negative absolute values of the parameters are rather high. Thus, the results suggest that this lagged error correction term makes a quantitatively important contribution in predicting future changes in factor shares.

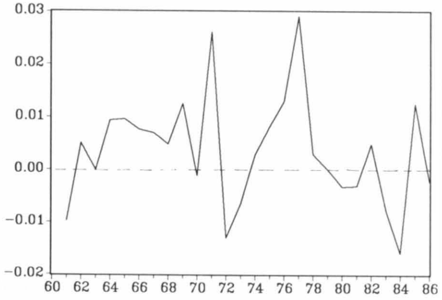


Figure 5. Capital cost share.

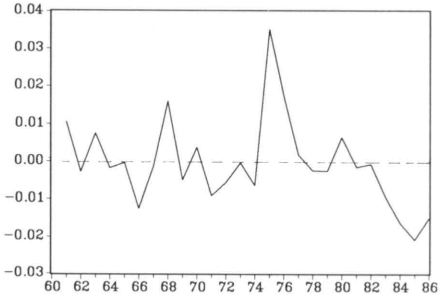


Figure 6. Labour cost share.

The DW statistic indicates that the null hypothesis of no first order serial correlation cannot be accepted for the capital share equation at the 5 % significance level, the other equations falling in to the inconclusive region of the test ($d_l = 0.98$ and $d_u = 1.88$). The test for first-order serial correlation as measured by Durbin's h -statistic indicates that this is not a problem for the electricity or capital factor share equations at the 5 % significance level (the critical value of the normal distribution is 1.645). In the labour and roundwood equations there appears to be some degree of first order autocorrelation. The h -test is generally considered to be more powerful than the DW test for testing models that include a lagged dependent variable.

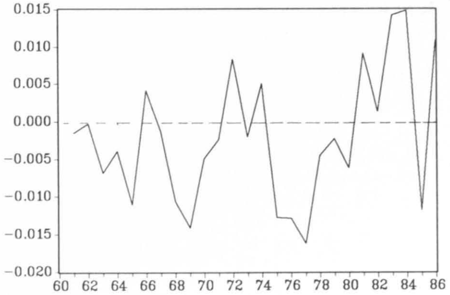


Figure 7. Electricity cost share.

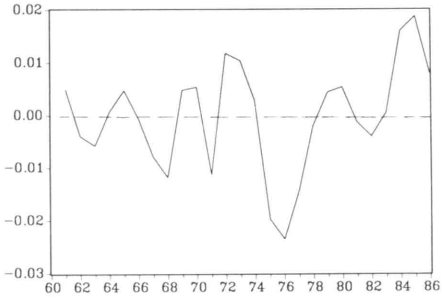


Figure 8. Roundwood cost share.

Finally, the equation-by-equation OLS estimations did not differ significantly from the system estimations. The absolute values of the error correction terms obtained from these estimations were (t values in parentheses): $Z_{K,t-1} = -0.66$ (—3.1); $Z_{E,t-1} = -0.48$ (—2.7); $Z_{L,t-1} = -0.38$ (—2.4); $Z_{M,t-1} = -0.52$ (—3.5). Thus, in each of the factor share equations the error correction term was highly significant and the absolute values in line with those reported above.

Elasticity results

Having estimated both the long -and short-run equations, the properties of these functions are examined, and the different elasticity measures are derived by using the parameters of these equations and the elasticity formulas (2.14), (2.15) and (2.19). However, before the results are discussed, it should be recalled that, for a number of reasons, the elasticity estimates should be regarded with some caution. First, both the quantity (only 27 observations) and quality of the data have some weaknesses. Also, the multicollinearity problem may be present in the static factor demand model, which was estimated using annual data for the price levels.[3] Furthermore, it should be borne in mind that the aggregate pulp industry data does not reveal differences in energy or raw material intensities, not in the input and output mixes of alternative pulp processes (i.e., mechanical, semi-chemical, sulphite and sulphate pulp).

First, it was checked whether the results are consistent with the regularity conditions set by theory. The underlying cost function is well-behaved, if it satisfies the monotonicity and concavity conditions. Monotonicity is satisfied if all the fitted cost shares are positive. A necessary condition for concavity is that all own-price elasticities are negative, while a necessary and sufficient condition is the negative semi-definiteness of the bordered Hessian matrix based on the estimated parameters of the cost function (i.e., the second order partial derivatives). It was found that the monotonicity of the cost function was assured by positive fitted cost shares at all sample points. Furthermore, the Hessian matrix based on the ZI3SLS parameter estimates was found to be negative semi-definite, evaluated at the sample mean. The Allen substitution elasticities and the own and cross-price elasticities are shown for each year of the data in the Appendix. However, for the sake of simplicity, only the elasticity figures which have been calculated at the mean values of the cost shares are shown below. Moreover, since the Allen substitution elasticities and the price elasticities are almost proportional, only the latter, more informative measures are presented. The "long-run" price elasticities calculated from the static equations (5.2) and from the parameter restrictions (for labour) are shown in Table 9.

The respective "intermediate" elasticities, i.e., after the short-run error has been corrected by the amount of the adjustment parameter, are derived by multiplying the parameters of the long-run equations (5.2) by the respective error correction term ($Z_{i,t-1}$) parameters and using the elasticity formulas. These elasticities are shown in Table 10. It should be noted that the "short-run" elasticities could in principle be calculated using the parameters of equations (5.3), but since their interpretation is not straightforward (they do not necessarily reflect the underlying theory), they have not been calculated here.

The own-price elasticities of demand measure the precentage change in the use of a given input resulting from a 1 % change in its price. In accordance with cost minimizing principles these elasticities should be negative. For example, a rise in the price of roundwood in relation to other production factors should lead to a substitution away from roundwood and thus decrease its use in production. All the "long-run" and "intermediate" own-price elasticities are negative and inelastic for roundwood, capital and labour (i.e., less than unity), while for electricity the demand is very elastic. Thus, if the price of electricity were to rise by 1 %, the demand for it would decrease by 2.37 % in the long-run and by 1.63 % in the intermediate stage. The "full" own-price elasticities indicate that once the output effects are factored in, the possibilities for substitution are reduced.

Considering the cross-price elasticities, substitutability dominates complementarity. The most surprising results concern labour and capital. According to the results, labour and capital are strong complements. This result is not in line with the common result of labour-capital substitutability. However, it may be noted that Wibe's (1987) results also indicated that labour and capital are complements in the Swedish chemical pulp industry. According to Wibe, the result" ...that labour and capital are complements need not be unrealistic considering the very specified process involved here. Of course capital and labour, in general, are substitutes, but for well defined processes there may be such a limited design of machines, that a perfect complementarity exists." (op. cit., p. 11).

The results also show that electricity and roundwood are complements, all the other input mixes being substitutes. In general, the results indicate that in the Finnish pulp industry there exist significant substitution possibilities in the input structure. Furthermore, it may be noted that factor substitution should be stronger in the long-run compared to the short-run, according to the "Le Chatelier" principle (see, for example, Varian 1978). This requires that negative own-price and positive cross-price elasticities should be larger and negative cross-price elasticities smaller in absolute value in the long-run compared to the short-run. This condition is satisfied in the majority of cases.

Table 9. "Long-Run" elasticities.

	e_{ii}	E_{ii}	e_{ij}	E_{ij}
M-M	-0.97	-1.20		
K-K	-0.52	-0.67		
L-L	-0.64	-1.02		
E-E	-2.37	-2.61		
M-K			0.52	0.36
M-L			1.26	0.88
M-E			-0.81	-1.05
K-L			-3.09	-3.46
K-E			2.76	2.52
K-M			0.85	0.62
L-K			-1.16	-1.31
L-E			0.79	0.42
L-M			1.00	0.77
E-M			-0.79	-1.02
E-K			1.62	1.46
E-L			0.41	0.04

Table 10. "Intermediate" elasticities.

	e_{ii}	E_{ii}	e_{ij}	E_{ij}
M-M	-0.89	-1.13		
K-K	-0.62	-0.78		
L-L	-0.64	-1.01		
E-E	-1.63	-1.87		
M-K			0.39	0.23
M-L			0.93	0.56
M-E			0.16	-0.07
K-L			-2.02	-2.39
K-E			1.98	1.74
K-M			0.62	0.39
L-K			-0.75	-0.91
L-E			0.68	0.44
L-M			0.59	0.36
E-K			1.17	1.01
E-L			1.05	0.68
E-M			0.17	-0.06

The above elasticity results were calculated using the mean value of the factor shares over the entire period investigated. However, it is interesting to examine whether the estimated elasticities are sensitive to the choice of observation period. In order to do this, the overall period was divided into two sub-periods which roughly correspond to the periods before and after the "energy crises" (i.e., 1960—1974 and 1975—1986), and the elasticities were computed using the mean factor shares from these sub-periods. It should be noted, that this type of analysis is only a very crude approximation of the possible effects of the energy crises on the elasticity measures. If the primary interest of the study had been on the effects of the energy crises, a model which allows gradual changes in the parameters over time would have been more appropriate (see, e.g., Ilmakunnas & Törmä 1989).^{4} The "long-run" elasticities for the two sub-periods are shown in Table 11.

Table 11. "Long-Run" elasticities for "1960—1974" and "1975—1986".

	1960-1974	1975-1986
e_{ii}		
M-M	-0.96	-0.98
K-K	-0.47	-0.57
L-L	-0.60	-0.69
E-E	-2.36	-2.40
e_{ij}		
M-K	0.47	0.59
M-L	1.27	1.24
M-E	-0.78	-0.85
K-L	-4.04	-1.90
K-E	3.48	1.86
K-M	1.03	0.62
L-K	-1.04	-1.30
L-E	0.91	1.12
L-M	0.73	0.87
E-K	1.56	1.70
E-L	0.46	0.35
E-M	-0.77	-0.81

Only a few general remarks concerning the above results are made. First, for each of the four production factors the own-price elasticity is greater in the period after the energy crises than the period before it. However, with the exception of capital input, the changes are very small. Secondly, the most significant changes in the cross-price elasticities have been in the capital input elacticities. In particular, capital-labour complementerity and capital-roundwood and capital-electricity substitutability are much smaller in the latter sub-period. All the other cross-price elasticities appear to be fairly stable between the two sub-periods.

As was pointed out earlier, the time trend has been used as an index for technical progress. There is some ambiguity in this, since our T variable measures all the changes that occur over time and which affect the factor shares. Accordingly, the index also measures such things as the effects of the switch from sulphite pulp to sulphate and mechanical pulp. Bearing these reservations in mind, the effects of technical change are examined by investigating the T parameters in equations (5.2). All the T parameters are highly significant according to the t values. The results indicate that technical change in the pulp industry has been roundwood -and electricity-"saving", and capital -and labour -"using". However, with the exception of capital, the elasticity measures are small in absolute value, indicating only minor effects of technical change on relative levels of input usage. For example, the T parameter for the labour share equation, calculated from the parameter restrictions, is + 0.0003, indicating almost neutral technical change.

Finally, comparing the elasticity figures derived in the present study to those obtained in the studies discussed in Section 24. is difficult for a number of reasons. First, the bulk of the studies have examined the aggregate pulp *and* paper industry. Furthermore, the specification of the technology, the estimation methods and the measurement of the empirical variables, the time period investigated and the countries where the industry is located differ between the studies. However, one "consistent" result may be pointed out. The own -and cross-price elasticity results obtained from the present study are in general somewhat higher than those derived in the other studies. The differences are particularly important for the own -and cross-price elasticity of the energy input. Whether this result is due to the fact that the energy variable in the present study is electricity, not an aggregate of all the energy forms as in the other studies, or due to something else, is difficult to judge.

53. The paper industry

Results of the long-run model

Analogous to the pulp industry case, the factor demands of the paper industry were estimated assuming constant returns to scale technology. In the paper industry the materials input in represented by the aggregate pulp input. This procedure was adopted because of the problems of constructing the price series for the aggregate materials input. The Industrial Statistics do not report the aggregate quantity of the materials factor; only the value of materials used in current prices is presented. Thus, the price of the materials input cannot be determined on the basis of the Industrial Statistics. One way around this problem would be to use the price indices of imported materials (see e.g., Törmä 1987). However, this requires making the assumption that the domestic and foreign materials are perfect substitutes for each other, so that their prices are the same. In order to avoid making this assumption, the pulp input is used to represent the materials input. It should also be noted that the pulp input has the desirable property of being a relatively homogeneous factor input. Finally, in the model of the paper industry production technology, it has been implicitly assumed that the K, L, E and M inputs are, as a group, weakly separable from the residual energy and materials inputs.

The cost share equation system was estimated using the Zellner iterative method and with the homogeneity and symmetry restrictions imposed on the parameters. In order to avoid singularity, the pulp share equation was dropped. The initial estimation results indicated that the values of the time trend coefficients in the labour and electricity factor share equations were not significant, the absolute values of the parameters also being very low. It should be remembered that the t values of the time trend variables have the standard normal distribution, even if series following an integrated process are included in the equation system (see, footnote 5). In addition, the results from preliminary estimations (i.e., the comparison of the actual and fitted cost shares) showed that the fit of the equations could be improved by introducing a dummy variable to take account of the "structural changes" which seem to have occurred after the energy crises in the mid 1970's. Consequently, in the final equation system the time trend variable was included only in the capital share equation and an additive dummy variable (D75), which obtained the value zero before 1975 and the value one thereafter, was included in each of the factor share equations. The results from the estimations are presented below.

$$(5.4)\quad S_L = \underset{(22.78)}{0.212} + \underset{(3.85)}{0.106} lnP_L - \underset{(-14.62)}{0.335} lnP_K + \underset{(1.32)}{0.041} lnP_E + \underset{(7.64)}{0.187} lnP_M + \underset{(5.85)}{0.04} D75$$

$$\bar{R}^2 = 0.97$$

$$S_K = \underset{(0.61)}{0.015} - \underset{(-14.62)}{0.335} lnP_L + \underset{(4.38)}{0.137} lnP_K + \underset{(2.46)}{0.076} lnP_E + \underset{(3.44)}{0.122} lnP_M + \underset{(9.00)}{0.008} T + \underset{(6.82)}{0.043} D75$$

$$\bar{R}^2 = 0.96$$

$$S_E = \underset{(25.33)}{0.288} + \underset{(1.32)}{0.041} lnP_L + \underset{(2.46)}{0.076} lnP_K + \underset{(2.50)}{0.173} lnP_E - \underset{(-5.52)}{0.290} lnP_M - \underset{(-4.13)}{0.035} D75$$

$$\bar{R}^2 = 0.90$$

The actual and fitted values of the equations are shown in the Appendix.

In order to be able to make valid inferences from the above results, the properties of the underlying time series and the residuals of the equations must be examined. The results from the autocorrelation functions and integration tests of the time series are shown in Tables 12—14. The augmented Dickey-Fuller test were not computed, since none of the series appeared to have significant higher order autoregressive processes (see Appendix). The actual and fitted cost shares are shown in Appendix.

The critical values for the CRDW and DF tests were reported in Section 52. The results from the autocorrelation functions and the cointegration tests show that the differences of the lnP_K and lnP_L series are not stationary, while all the other series appear to be I(1) processes. Again, further examination of the autocorrelation functions for the second differences of the lnP_K and lnP_L series, shown below, indicated that these series might follow I(2) process.

Autocorrelation functions

Series lag:	1	2	3	4	5
$\Delta\Delta lnP_L$	−0.074	−0.094	−0.220	−0.078	0.081
$\Delta\Delta lnP_K$	−0.199	−0.152	0.033	−0.175	0.099

Analogous to the pulp industry case, it was tested whether the first differences of the capital and labour price series are cointegrated. The CRDW and DF test results from regressing ΔlnP_K on ΔlnP_L were 1.21 and —3.05, respectively. The tests statistics from regressing ΔlnP_L on ΔlnP_K were 1.26 for the CRDW test and —3.34 for the DF test. Therefore, on the basis of the CRDW test, the hypothesis of significant unit root can be rejected at the 5 % significance level, while the DF test indicates that the hypothesis of significant unit root can be rejected at the 10 % level (according to the Engle & Yoo 1987 critical values). Furthermore, the autocorrelation functions of the residuals from the two regression equations indicated that the residuals are stationary (the first autocorrelation coefficient for both residuals were below 0.360 and it declined rapidly with increases in lag).

Table 12. Aurocorrelation functions of the series.

Series	lag: 1	2	3	4	5
lnP_L	0.906	0.806	0.701	0.595	0.489
ΔlnP_L	0.570	0.232	0.005	-0.060	-0.074
$\ln P_K$	0.912	0.811	0.707	0.601	0.488
ΔlnP_K	0.539	0.297	0.190	0.005	0.008
lnP_E	0.937	0.843	0.749	0.645	0.526
$\Delta\ln P_E$	0.080	0.082	0.231	-0.081	0.217
lnP_M	0.922	0.827	0.718	0.618	0.517
$\Delta\ln P_M$	0.336	-0.309	-0.347	0.001	0.251
S_L	0.855	0.707	0.542	0.423	0.318
ΔS_L	0.007	0.218	-0.176	0.111	0.136
S_K	0.897	0.795	0.692	0.578	0.463
ΔS_K	0.109	0.149	-0.079	-0.259	0.120
S_E	0.819	0.640	0.452	0.306	0.201
ΔS_E	-0.059	0.057	-0.130	-0.183	-0.108
S_M	0.895	0.789	0.712	0.622	0.508
ΔS_M	0.036	-0.149	-0.099	-0.155	0.236

Table 13. Sargan-Bhargava CRDW test.

Series	CRDW	constant "t"	trend "t"
lnP_L	0.25	17.89	55.73
$\Delta\ln P_L$	0.75	6.23	-0.24
lnP_K	0.17	-1.63	21.87
ΔlnP_K	1.02	0.80	2.55
$\ln P_E$	0.36	25.04	16.31
$\Delta\ln P_E$	1.60	0.36	0.81
lnP_M	0.50	79.34	19.83
$\Delta\ln P_M$	1.31	1.14	0.13
S_L	0.23	33.90	-2.73
ΔS_L	2.46	1.98	-2.65
S_K	0.39	6.32	14.69
ΔS_K	1.70	0.67	0.61
S_E	0.76	30.36	11.71
ΔS_E	2.13	-0.01	0.75
S_M	0.34	46.41	-15.08
ΔS_M	1.56	-1.99	0.79

Table 14. DF tests ("t" -values).

Series	DF	constant	trend
$lnP_{L(-1)}$	-1.01	3.07	0.99
$\Delta\ln P_{L(-1)}$	-2.13	2..13	-0.85
$lnP_{K(-1)}$	-2.38	0.03	3.00
$\Delta\ln P_{K(-1)}$	-2.52	0.85	0.73
$lnP_{E(-1)}$	-1.46	1.64	1.44
$\Delta lnP_{E(-1)}$	-3.80	1.17	0.01
$lnP_{M(-1)}$	-2.02	2.10	1.99
$\Delta\ln P_{M(-1)}$	-3.26	0.85	0.41
$S_{L(-1)}$	-1.07	1.36	-2.87
$\Delta S_{L(-1)}$	-5.96	2.21	-2.79
$S_{K(-1)}$	-1.79	1.76	1.90
$\Delta S_{K(-1)}$	-4.09	0.31	0.66
$S_{E(-1)}$	-2.69	2.64	2.79
$\Delta S_{E(-1)}$	-5.13	0.28	0.48
$S_{M(-1)}$	-1.09	0.86	-0.79
$\Delta S_{M(-1)}$	-3.77	-1.40	0.65

Consequently, it is possible that all the variables in the factor demand model for the paper industry form a cointegrating set. In order to establish whether this is indeed the case, the autocorrelation functions and cointegration tests for the residuals of the factor share equations were computed. The results together with the graphs of the residuals are shown in Tables 15—16 and in Figures 9—12.

The autocorrelation functions are all below 0.5 and they decline rapidly as the lag increases, therefore indicating that the residuals may be stationary. The CRDW test results support this conclusion as well (the Engle & Yoo 1987 critical value at the 5 % significance level is 0.78). However, the DF test shows that, while the labour and pulp factor share equations are cointegrated, the capital and electricity factor share equations do not appear to be cointegrated. Since the labour and electricity factor share equations seem to follow a higher order autoregressive process (see Appendix 2), the ADF test was computed for these equations. The results of the ADF test indicate that these factor share equations are cointegrated.

It should be noted that the cointegration results are somewhat sensitive to the inclusion of the time trend and dummy variables. For example, the CRDW test results for the residuals obtained from the equation system without the time trend and dummy variables indicated that the factor share equations are

Table 15. Autocorrelation functions of the residuals.

Residual	lag: 1	2	3	4	5
ε_L	0.276	-0.029	-0.141	-0.368	-0.200
ε_K	0.491	0.081	-0.101	-0.042	-0.113
ε_E	0.469	-0.061	-0.196	-0.375	-0.421
ε_M	0.349	-0.187	-0.228	0.141	0.309

Table 16. Cointegration tests.

Residual	CRDW	DF ("t"-values)	ADF
ε_L	1.37	-3.35	-3.37
ε_K	0.97	-2.97	
ε_E	1.02	-2.99	-3.82
ε_M	1.23	-3.55	

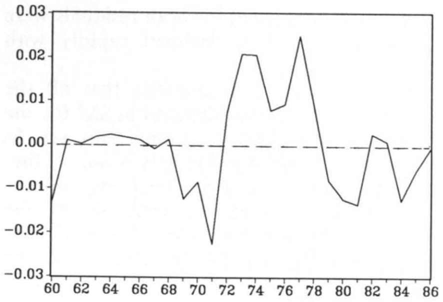


Figure 9. Capital cost share. — *SKRESIDUAL*

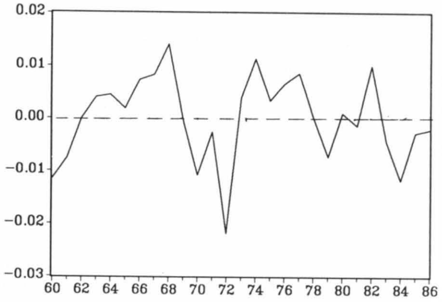


Figure 10. Labour cost share. — *SLRESIDUAL*

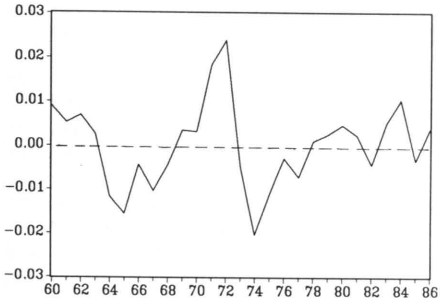


Figure 11. Electricity cost share. — *SERESIDUAL*

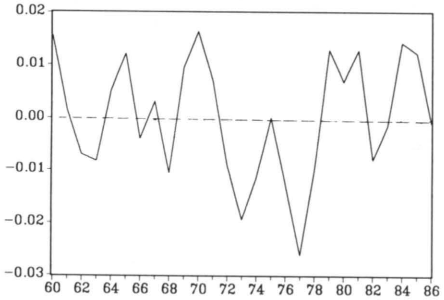


Figure 12. Pulp cost share. — *SPRESIDUAL*

not cointegrated at the 5 % significance level according to the Engle & Yoo (1987) critical values. On the other hand, if the Engle & Granger (1987) critical values are used, all the factor share equations appear to be cointegrated. Furthermore, if the symmetry and homogeneity restrictions are relaxed, the results from the CRDW test show that all the factor share equations are also cointegrated on the basis of the Engle & Yoo (1987) critical values. Consequently, as in the pulp industry case, it appears that the cointegration results for the paper industry are not really sensitive to the inclusion of "deterministic" variables as such, but rather to the theoretical restrictions on the parameters.

The above results from the integration and cointegration tests imply that although the t and R^2 statistics are biased, the parameter estimates are consistent. Furthermore, the results also imply that the second stage of the Engle & Granger procedure can be estimated. Coinsequently, the dynamic, short-run equation systems were estimated using the Zellner iterative method. Since the estimation procedure of the dynamic model for the paper industry is analogous to the pulp industry case, it is not repeated here (see section 52.). The estimation results for the dynamic system in which the dependent cost shares are labour, electricity and pulp are shown below. The actual and fitted values of the equations are shown in the Appendix.

(5.5)

$$\Delta S_L = -0.010\Delta lnP_L - 0.164\Delta lnP_K - 0.053\Delta lnP_E + 0.227\Delta lnP_M - 0.787Z_{L,t-1}$$
$$\quad (-0.08) \quad (-1.50) \quad (-0.54) \quad (2.08) \quad (-5.53)$$
$$DW = 1.79 \qquad h = 1.04 \qquad \bar{R}^2 = 0.17$$

$$\Delta S_E = 0.197\Delta lnP_L - 0.109\Delta lnP_K + 0.261\Delta lnP_E - 0.349\Delta lnP_M - 0.741Z_{E,t-1}$$
$$\quad (1.45) \quad (-0.98) \quad (2.56) \quad (-3.02) \quad (-4.95)$$
$$DW = 1.78 \qquad h = 0.87 \qquad \bar{R}^2 = 0.27$$

$$\Delta S_M = -0.039\Delta \ln P_L - 0.128\Delta \ln P_K - 0.105\Delta \ln P_E + 0.272\Delta lnP_M - 0.495Z_{M,t-1}$$
$$\quad (-0.26) \quad (-1.06) \quad (-0.94) \quad (2.19) \quad (-3.64)$$
$$DW = 1.90 \qquad h = 0.35 \qquad \bar{R}^2 = 0.40$$

The capital share equation results, shown below, were obtained from the system in which labour and electricity formed the other two factor share equations.

$$\Delta S_K = -0.138\Delta lnP_L + 0.386\Delta lnP_K - 0.084\Delta lnP_E - 0.164\Delta lnP_M - 0.532Z_{K,t-1}$$
$$\quad (-1.01) \quad (3.48) \quad (-0.82) \quad (-1.41) \quad (-3.79)$$
$$DW = 2.03 \qquad h = -0.11 \qquad \bar{R}^2 = 0.49$$

The residuals of the dynamic cost share equations are shown in Figures 13—16.

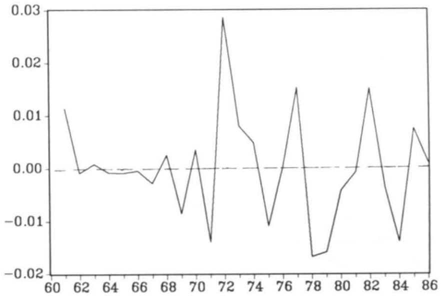


Figure 13. Capital cost share. — *DSKRESIDUAL*

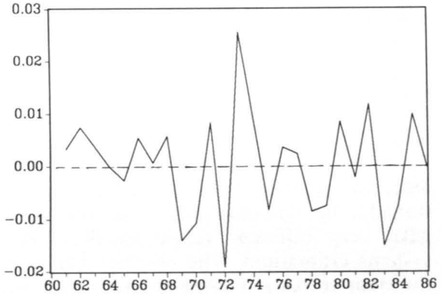


Figure 14. Labour cost share. — *DSLRESIDUAL*

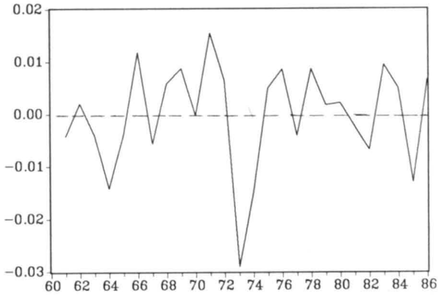


Figure 15. Electricity cost share. — *DSERESIDUAL*

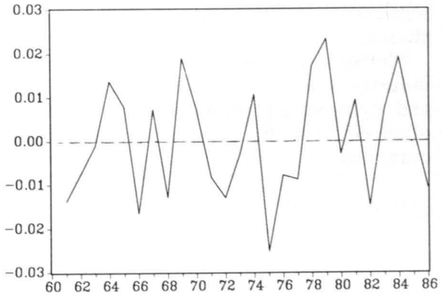


Figure 16. Pulp cost share. — *DSPRESIDUAL*

Because of the problems of interpreting both the absolute values and the t statistics of the factor price parameters (see Section 52.), the estimation results concerning these coefficients are not discussed here. The results support the error correction specification, each error correction term ($Z_{i,t-1}$) being highly significant according to the t values. The absolute values of the error correction terms are rather high, suggesting fairly rapid adjustment to short-run shocks. The DW statistic shows that the labour and electricity cost share equations fall into the inconclusive region of the Durbin-Watson statistic, while the null hypothesis of no serial correlation can be accepted for the pulp and for the capital cost share equations. The results for Durbin's h-statistic show that the null hypothesis of no first order serial correlation can be accepted for each of the cost share equations. The graphs of the actual and fitted cost shares are shown in the Appendix.

Finally, it should be noted that the results did not differ significantly between the four different equation systems estimated. Therefore the results are not very sensitive to which of the four equations is omitted. However, in contrast to the pulp industry case, the equation-by-equation OLS estimations for the dynamic paper industry model gave very different result to the above systems estimations. The absolute values of the error correction terms obtained from the OLS estimation were (t-values in parentheses): $Z_{K,t-1} = —0.15$ (—0.78); $Z_{L,t-1} = —0.26$ (—0.96); $Z_{E,t-1} = —0.12$ (—0.58); and $Z_{M,t-1} = —0.38$ (—1.77). Thus, all the error correction terms fail to be statistically significant and their absolute values are significantly smaller than those obtained from the systems estimations. Consequently, the paper industry results appear to be sensitive to the specific estimation method chosen.

Having estimated the complete paper industry model, the properties of the static and dynamic equations and the elasticities obtained from the estimated parameters are examined.

Elasticity results

It was stated above that the time trend variable was significant only in the capital share equation and that the static model appeared to give a better fit when dummy variables were included. Bearing in mind the problems of representing technical change by a time trend variable (see Section 52.), the results indicate that technical change in the paper industry has been capital-using. The implication of this is that technical change has been pulp-saving (because of the adding up restriction). The dummy variable parameters are statistically significant, suggesting that there has been a structural change which is probably connected with the post-energy-crises recession. The positive dummy for the capital and labour share equation indicates that, ceteris paribus, the cost shares of these factors increased as a result of the energy crises. On the other hand, the negative dummy for electricity points to a reduction in the electricity cost share in the total cost of producing paper. Furthermore, these results imply (via the adding up restriction) that the share of pulp must have declined after the energy crises.

Turning to the underlying theoretical restrictions, it was found that the monotonicity condition was assured by positive fitted cost shares at all sample points. Furthermore, the own-price elasticities show that the labour and pulp inputs have the correct sign, but that the capital and electricity inputs have the wrong positive sign at some sample points (see the Appendix). In particular, the elasticity of the capital input has the wrong sign for observations in 1960—1973, while the elasticity of the electricity input has the wrong sign for each year in 1960—1979, except 1972. Thus, the necessary condition for concavity is violated. One possible reason for the failure of the model to fulfil the concavity restriction may be the weaknesses of the data.

However, it should be noted that the violation of the concavity condition is not unusual in empirical studies and, moreover, it is not necessarily critical. Donnely (1987) states in the context of discussing the failure of translog functions to satisfy theoretical conditions that, "the failure of empirical results to satisfy various functional constrains required for well-behaved models is not unusual. ..., the nature of the translog, in that it represents a local approximation to the underlying function solely, may suggest an imperfect fit of whatever data are available to the basic hypothetical structure of the model" (op. cit. p. 183). Also, Wales (1977) has argued that it is possible for the estimated price elasticity to be close to the true one and still have curvature violations. Furthermore, the violation of concavity or monotonicity conditions need not imply the absence of an underlying cost minimization process, but may simply reflect the inability of the flexible form to approximate the true cost function over the range of the data (see Wales (1977)).

Table 17. "Long-Run" elasticities.

	e_{ii}	E_{ii}	e_{ij}	E_{ij}
M-M	-0.77	-1.07		
K-K	0.11	-0.05		
L-L	-0.34	-0.67		
E-E	0.04	-0.17		
M-K			0.20	0.04
M-L			0.38	0.06
M-E			0.12	-0.09
K-M			0.39	0.09
K-L			0.06	-0.26
K-E			0.23	0.02
L-M			0.35	0.05
L-K			0.05	-0.11
L-E			0.22	0.01
E-M			0.17	-0.13
E-K			0.18	0.02
E-L			0.33	0.01

Table 18. "Intermediate" elasticities.

	e_{ii}	E_{ii}	e_{ij}	E_{ij}
M-M	-0.73	-1.03		
K-K	-0.33	-0.50		
L-L	-0.42	-0.74		
E-E	-0.73	-1.03		
M-K			0.17	0.01
M-L			0.36	0.03
M-E			0.19	-0.49
K-M			0.35	0.05
K-L			0.19	-0.14
K-E			0.22	0.01
L-M			0.34	0.04
L-K			0.14	-0.03
L-E			0.21	0.004
E-M			0.20	-0.10
E-K			0.16	0.001
E-L			0.34	0.02

Table 19. "Long-Run" elasticities.

	1960-1974	1975-1986
e_{ii}		
M-M	-0.72	-0.83
K-K	0.33	-0.16
L-L	-0.35	-0.34
E-E	0.08	-0.0004
e_{ij}		
M-K	0.16	0.26
M-L	0.41	0.34
M-E	0.10	0.15
K-M	0.46	0.29
K-L	-0.02	0.16
K-E	0.22	0.24
L-M	0.40	0.29
L-K	-0.002	0.13
L-E	0.20	0.23
E-M	0.17	0.17
E-K	0.13	0.24
E-L	0.36	0.31

The "long-run" price elasticities computed from the static equations (5.4) and from the parameter restrictions (for pulp) using the elasticity formulas, are shown in Table 17. It should be recalled that the elasticities are calculated using the mean values of the cost shares.

Perhaps the most interesting results concerning the long-run elasticities are that all the own -and cross-price elasticities are quite small compared to the pulp industry case. Also, each of the cross-price elasticities is positive, indicating that all factors are substitutes. However, the "full" cross-price elasticities show that, once the output effects are taken into account, the possibilities for substitution are reduced, some of the factors even becoming complementary. Furthermore, the full own-price elasticities of the capital and electricity inputs have the correct negative sign.

The "intermediate" elasticities are given in Table 18. The results indicate that, in general, the differences in the long-run and intermediate elasticities are rather small. In the majority of the cases the substitution possibilities are somewhat lower in the intermediate stage than in the long-run, and thus the results are to large extent consistent with the "Le Chatelier" principle. The most significant differences between the long-run and the intermediate stage are in the own-price elasticities, which in the intermediate stage have the correct negative sign for each of the factor inputs.

Finally, the long-run elasticities using the mean values of the factor shares from the periods before and after the energy crises, i.e., 1960—1974 and 1975—1986, were computed. The results are shown in Table 19.

The interesting points to note about the above results are that the own-price elasticities between the two sub-periods do not differ significantly.

Since the difficulties of comparing the results obtained in the present study with those obtained in other studies have already been mentioned (see section 52.), only a few remarks are made here. First, the own -and cross-price elasticities obtained for the paper industry do not differ greatly from those reported, for example, in Törmä & Loukola (1986), Sherif (1983) and Stier (1985). In fact, in Törmä & Loukola (1986), the study closest to the present one, the elasticities results are very similar to ours. For example, the own-price elasticities for capital, labour and materials inputs in Törmä & Loukola were 0.063, —0.302 and —0.465, respectively. Also, the capital-labour (0) and labour-materials (0.298) substitution elasticities were similar to the long-run elasticities obtained in the present study. It is hard to judge whether the similarity of the results can be regarded as supporting the underlying models, or whether the similarity is merely due to chance.

Footnotes

1. In principle, only weak exogeneity is required in our empirical model since the model is used solely for testing hypotheses, not for forecasting or policy simulation. Weak exogeneity means in the present context that the stochastic structure of the right hand side variables of our model is irrelevant as regards any inference about the parameters of interest. Surprisingly, however, this does not mean that the independent and dependent variables may not be "Granger caused" by each other. Indeed, one consequence of the error-correction model is that either S_i or lnP_i (or both) must be caused by $Z_{i,t-1}$, which is itself a function of $S_{i,t-1}$, $lnP_{i,t-1}$. Thus, either $S_{i,t+1}$ is (Granger) caused in means by $lnP_{i,t}$ or $lnP_{i,t+1}$ by $S_{i,t}$ if the series are cointegrated. According to Granger (1988), "This is a somewhat surprising result, when taken at the face value, as cointegration is concerned with the long run equilibrium, whereas the causality in mean is concerned with the short run forecastability. However, what it essentially says is that for a pair of series to have an attainable equilibrium, there must be some causation between them to provide the necessary dynamics" (op. cit., p. 203). For further discussion on the different definitions of exogeneity and the link between exogeneity and causality, see Engle et al. (1983).

2. According to Durlauf & Phillips (1988): "The results for the Durbin-Watson statistic appear quite promising for the empirical worker... The asymptotic behaviour of the Durbin-Watson statistic suggest that the probability of mistaking a nonstationary series for a stationary series about trend is not particularly great for reasonably large data sets. These results strongly reinforce the recommendations made recently by Sargan and Bhargava (1983) concerning the use of the Durbin-Watson statistics as a discriminatory device for unit roots." (op. cit., p. 1337).

3. If multicollinearity is present in the model, the interpretation of the regression parameters and the identification of their effects on the dependent variable will be difficult. A common method used to try to detect multicollinearity is to examine the simple correlations among regressors. In our static model, the simple correlation between the levels of the price variables ranged from 0.971—0.987, which could be an indication of multicollinearity. However, pairwise correlations can give no insight into more complex interrelationship among three or more variables. Furthermore, in our model we have imposed linear restrictions on the parameters, which tend to reduce the covariance of the estimators by augmenting the sample data with nonsample data. Thus, whether multicollinearity is actually a problem for the present model is difficult to judge.

4. In principle, we could have tested whether there has been a structural change in the parameters after the energy crises (e.g., using the Chow-test). However, since the underlying time series follow an integrated process, the statistic based on the F-test would not have been valid. Furthermore, there would have been a problem of degrees of freedom in the sub-period estimations.

5. Although equations (5.3) include series which follow an integrated process, the T parameters have the conventional large-sample properties (see Stock & Watson 1988, p. 167).

6. Summary and conclusions

The motivation for the present study originated from two observations. First, there are very few econometric studies on factor demand in the Finnish pulp and paper industries. Although there have been few studies which have touched on the issue of factor substitution in the pulp and paper industries, no study has thoroughly examined the subject. There is, for example, no empirical evidence on the dynamics of factor demand, nor are there any results on the substitution elasticities between some of the factor inputs (e.g., roundwood input and energy). Consequently, the need for further empirical evidence is apparent. Secondly, the recent methodological advances in modelling dynamic adjustment and integrated time series have not yet been applied in the Finnish or foreign factor demand (systems) literature. Therefore, the aim of the present study has been to provide new empirical results and to apply a new methodological approach in the context of a flexible functional form model of factor demand. This concluding chapter summarizes the study, examines the conclusions that can be drawn on the basis of the empirical investigation and makes some suggestions as regards possible improvements in the empirical results.

Chapter 2 set the background of the study and introduced various concepts and theoretical and empirical approaches relevant to the study. A survey of the Finnish and foreign literature on factor demand in the forest industry was also provided.

In Chapter 3, the characteristics of the Finnish pulp and paper industries were discussed. In addition, the theoretical framework of the study was presented and the long-run static and short-run dynamic models of factor demand were derived.

The long-run model is based on neoclassical production theory. It was assumed that in the Finnish pulp and paper industries there exists a production function which relates the services of labour, capital, energy and materials to the flow of output. Furthermore, it is known that such a production function has, under some general conditions, a dual cost function which summarizes all of the economically relevant aspects of the industries' technology. In order to operationalize the model for empirical estimation a flexible translog cost function was specified and the input demand equations were derived using Shephard's Lemma. In the recent literature, the static translog cost function model has been the most common approach in modelling factor demand in the forest industry.

One of the main concerns in the present study has been the modelling of the dynamics of factor demand. In this respect the study differs significantly from previous studies. The conventional way of introducing dynamics in the factor demand model is to assume strictly convex adjustment costs for one of the inputs (capital or labour), or to impose some ad hoc lag structure on the model. In this study, the dynamics is modelled using an error correction model, which is strictly linked to the underlying data generation process. In particular, the results from the literature on integrated time series and cointegration are used to model the dynamics of factor demand. Whether the underlying time series in the model follow an integrated process or not has important implications not only for dynamic modelling, but also for the validity of the static model. If the time series in the factor demand model are non-stationary, the estimated parameters are not normally distributed and statistical inference based on, for example, conventional t and F values is not valid. As it appears that the time series data required to estimate industry factor demand models may well follow an integrated process, the results from previous studies using conventional estimation methods may be subject to the above problem.

It was further pointed out that the "Granger Representation Theorem" shows that, if the underlying time series are integrated and form a cointegrated relationship, there exists an error correction model which links the short-run dynamics to long-run behaviour and provides a valid representation of the data. In contrast to the conventional approaches, the error correction model does not restrict any of the factors to be quasi-fixed, so each factor is allowed to adjust at its own rate. Engle & Granger (1987) have presented a two-step estimation method which can be used to estimate the error correction model consistently. Finally, this estimation procedure was described in the context of the static factor demand model and the advantages and weaknesses of the approach were evaluated.

Chapter 4 presented the econometric models and estimation results for the pulp and paper industries. In order to be able to implement the theoretical models empirically, some further assumptions were made. The assumptions used in the models are: 1) the cost function can be represented by a homothetic translog approximation, 2) technical change can be represented by a linear time trend, 3) inputs can be aggregated into four categories: capital, labour electricity and roundwood (pulp industry) or pulp (paper industry). Because of the small number of observations in the data, the inherent collinearity of the variables in the cost function and the difficulties of dynamic parameterization of the cost function, only the cost share equations were estimated. As regards the data used for estimating the models, a number of choices had to be made in the definitions of the appropriate variables, the measurement of the raw data and the aggregation methods, all of these choices having potential bearing on the results obtained. Both the long-run and short-run systems of cost share equations were estimated using the Zellner iterative method. The theoretical restrictions of symmetry, homogeneity and adding up were imposed on the long-run equations, but only the adding up condition was imposed on the short-run equations.

The properties of the underlying time series and the residuals of the cost share equations were examined in detail. The results from the autocorrelation functions, integration and cointegration tests indicated that the cost share equations in both the pulp and paper industries could be accepted for forming cointegration relationships. This implied that tests based on normal distribution could not be used to make inferences about the results of the long-run model. The other implication of these tests was that the Engle & Granger two-step estimation method could be used to estimate the error correction representations of the models.

The estimation of the dynamic cost share systems was not a straightforward procedure. In the literature, the studies by Anderson & Blundell (1982) and Holly & Smith (1989) are the only ones in which dynamic singular equation systems employing a multivariate error correction model have been estimated. As is stated in these studies, there are no tractable restrictions on the lagged endogeneous error terms in the dynamic system. Therefore in the above type of models, the identification of the lagged error correction term of the omitted factor share equation is an unsolved problem. A pragmatic approach to this problem was adapted and all the possible combinations (i.e., four) of the cost share equation systems were estimated and the sensitiveness of the results to specification changes were examined. In addition, for the sake of comparison, the cost share equations using the equation-by-equation ordinary least squares method were estimated. For the pulp industry the results showed that the error correction terms were highly significant and the absolute values of the parameters rather high. Consequently, the results supported the error correction specification and indicated fairly rapid adjustment to short-run shocks. Furthermore, the results from the different combinations of the dynamic factor share systems and estimation methods (i.e., Zellner iterative and OLS estimations) were very similar. For the paper industry the results of the systems estimation indicated that the error correction terms were significant and their absolute values were fairly high in each of the factor share equations. However, the equation by equation OLS estimations results showed that the error correction specification failed to be significant for each of the factor share equations.

Finally, the Allen substitution elasticities, the own -and cross-price elasticities and the "full-price" elasticities were derived using different elasticity formulas. Elasticities were calculated both for the "long-run" equilibrium and for the "intermediate" stage, i.e., when the previous period disequilibrium has been corrected by the amount of the error correction term.

First, the negative semi-definite Hessian matrix and the positive fitted cost shares indicated that in the pulp industry theoretical concavity and monotonicity conditions were satisfied. The failure of the paper industry model to be consistent with the concavity restriction is probably a reflection of the weaknesses of the data or due to the fact that the translog function has the property of being only locally well-behaved.

Considering first the results from the pulp industry model, the own-price elasticities indicated that for each input the demand is sensitive to changes in its own price. The own-price elasticity is less than unity for capital, labour and roundwood, while it is very high for electricity (—2.37). In the intermediate stage, the respective elasticities are somewhat smaller. Also, the own-price elasticities do not appear to be sensitive to the observation period, the differences between the two sub-periods (1960—1974 and 1975—1986) being rather small. Turning to the cross-price elasticities, complementary relationships prevail between capital and labour and electricity and roundwood, while substitutability dominates all the other input mixes. In general, the results indicate that significant substitution possibilities do exist in the input structure. Furthermore, the intermediate stage elasticities show that the Le Chatelier principle is satisfied for the majority of the elasticity measures. Finally, the own -and cross-price elasticity results obtained in this study are, in general, somewhat higher compared to the results obtained in the previous studies.

Borne in mind the violation of the concavity condition, the results for the paper industry model indicate that both the own - and cross-price elasticities are quite small, in particular, compared to the pulp industry results. All the input mixes appear to be substitutes. The differences between the long-run and intermediate elasticities are small, the own price elasticities for capital and electricity inputs showing the greatest change. In fact, the sign of the own-price elasticity of capital and electricity has changed from the (wrong) positive sign in the long-run to the (correct) negative sign in the intermediate stage. In most cases, the elasticity estimates of the paper industry model are not very sensitive to the choice of observation period. However, the own -and cross-price elasticities involving the capital input show a degree of instability between the two sub-periods investigated. Finally, comparing the results to those obtained in the other studies, similarities are more evident than the differences. Indeed, the results appeared to be quite consistent with those obtained by Törmä & Loukola (1986).

Some reservations concerning the results must be made. First, the most serious shortcoming of the study is the small number of observations available for the estimation of the models. Since the statistical properties of the estimation methods used in the study are asymptotic, our results are subject to possible small sample bias. Also, the critical values and small sample properties of the integration and cointegration tests are unknown for a wide range of models. Furthermore, there is the problem of potential non-uniqueness of the cointegration vector in our models which include more than two variables.

It should also be noted that, owing to the non-stationarity of the underlying time series, it was not possible to test whether the homotheticity or the symmetry and homogeneity restrictions were valid. Besides these problems, the study may suffer from a number of other problems which tend to be common to all empirical applications of factor demand models based on time series data. These are problems such as potential multicollinearity between the independent variables in the factor share equations and incorrect aggregation and measurement of the data.

Finally, to conclude, a few suggestions concerning possible ways of improving the empirical results of this study are put forward. First, referring to Chapter 3, it was noted that Johansen's maximum likelihood estimation method can provide solutions to the problems of non-uniqueness of the cointegration vector and to the arbitrariness of the limiting distributions of the cointegration tests. It would be useful to try to develop this method so that it could be applied in context of the present model, i.e., in models where an equation system subject to parameter restrictions is estimated. Secondly, it would be interesting to compare the translog estimation results to those obatained by using the new forms of felxible functional forms which are globally well-behaved. Furthermore, as stated above, there are number of problems with the data base used in this study. Thus, improvement of the quantity and quality of the data should be one of the primary concerns in future research.

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Seloste

Panosten substituutio Suomen massa- ja paperiteollisuudessa

Tutkimuksen tausta ja tavoitteet

Suomen massa- ja paperiteollisuuden tuotannosta merkittävä osa viedään ulkomaille. Maailmanmarkkinoilla teollisuuden on sopeuduttava tuotteidensa markkina- ja hintakehitykseen ja mahdollisuudet vaikuttaa tuotantopanosten hintoihin ovat rajoitetut. Yritykset eivät tällöin voi siirtää suhteellisia panoshintojen nousua suoraan tuotteidensa hinnoitteluun menettämättä kilpailukykyään ja markkinaosuuksiaan. Näin ollen sopeutumisen panoshintojen muutoksiin on tapahduttava pääosin yrityksen tuotantoteknologiaa muuttamalla. Tällöin keskeinen kysymys massa- ja paperiteollisuudelle on se, kuinka joustavasti panosten käyttö reagoi niiden suhteellisten hintojen muutoksiin, ts. kuinka suuria ovat panosten kysyntöjen oman hinnan, risti- ja substituutiojoustot. Panosjoustojen selvittäminen ei ole tärkeää ainoastaan yrityksille, vaan myös viranomaisille, joilla esim. energia- ja metsäpoliittisia päätöksiä tehtäessä täytyy olla käsitys niiden yritystaloudellisista vaikutuksista.

Massa- ja paperiteollisuuden panoskysyntää käsittelevä ekonometrinen tutkimus on ollut suhteellisen vilkasta mm. Yhdysvalloissa ja Kanadassa, mutta Suomessa huomattavan vähäistä. Suomessa ei ole tutkittu massa- ja paperiteollisuuden raakapuu- ja energiapanoksen joustoja eikä myöskään panoskysynnän dynamiikkaa. Toisaalta, sekä ulkomaisessa että kotimaisessa aikasarja-aineistoa käyttävissä ekonometrisissa panoskysyntätutkimuksissa ei ole huomioitu eräitä viimeaikaisia tuloksia koskien muuttujien aikasarjaominaisuuksia. Näillä ominaisuuksilla on kuitenkin keskeinen merkitys tulosten tilastolliseen luotettavuuteen ja tulkintaan. Tämän tutkimuksen tavoitteena on soveltaa uutta ekonometrista panoskysyntämallia, jossa huomioidaan muuttujien aikasarjaominaisuudet ja panoskysynnän dynamiikka ja toisaalta tuottaa uutta informaatiota Suomen massa- ja paperiteollisuuden panoskysynnästä. Tutkimuksen teoreettisessa osassa johdetaan panosten kysyntäyhtälöt ja empiirisessä osassa estimoidaan pitkän ja lyhyen aikavälin ekonometriset panoskysyntämallit Suomen massa- ja paperiteollisuudelle..

Teoreettinen kehikko

Tutkimuksen teoreettinen kehikko perustuu neoklassiseen tuotantoteoriaan. Tutkimuksen lähtökohtana on oletus, että massa- ja paperiteollisuuden "edustavalle yritykselle" on olemassa tuotantofunktio, joka kuvaa tietyn aikayksikön kuluessa käytettyjen eri panosten ja suurimman mahdollisen niiden avulla valmistettavan tuotoksen välistä suhdetta. Tuotantofunktion oletetaan täyttävän ns. hyvin käyttäytyvän tuotantofunktion ominaisuudet. Lisäksi yritysten oletetaan minimoivan tuotantokustannuksia, ts. yrityksen optimointiongelma on minimoida tuotannon kokonaiskustannukset panoshintojen ja tuotannon tason ollessa annetut. Duaaliteoria mahdollistaa tuotantoteknologian kuvaamisen kustannusfunktiolla, jossa argumentteina ovat pääoman, työn, energian ja raaka-aineiden hinnat ja teknistä kehitystä kuvaava aikatrendi. Kustannusfunktiosta johdetaan panosten kysyntäfunktiot (kustannusosuusyhtälöt) käyttämällä Shephardin lemmaa, ts derivoimalla kustannusfunktiota panosten hintojen suhteen.

Tutkimus eroaa keskeisesti aikaisemmista panoskysyntämalleista, koska dynamiikan kuvaamiseen sovelletaan Grangerin erityslauseeseen perustuvaa virheenkorjausmallia. Menetelmä mahdollistaa tiettyjen aikasarjaominaisuuksien voimassa ollessa staattisen pitkän aikavälin yhtälön ja dynaamisen lyhyen aikavälin yhtälön konsistentin estimoinnin. Siten perusteet mallin dynaamiselle kuvaamiselle saadaan muuttujien tilastollisista ominaisuuksista eikä talousteoriasta sinänsä. Kyseistä lähestymistapaa ja tutkimuksessa käytettyä epästationaaristen aikasarjojen ekonometriaa (stationaarisuus ja yhteisintegraatiotestejä) ei ole aikaisemmin sovellettu panoskysyntäsysteemien mallitukseen.

Aineisto ja estimointimenetelmät

Tutkimusaineiston pääosan muodostivat Tilastokeskuksen Teollisuustilaston vuosittaiset aikasarjat vuosilta 1960—1986. Koska kyseisiin aikasarjoihin liittyy merkittäviä mittausvirheitä (mm. kaksoislaskentaa) koko massa- ja paperiteollisuuden toimialatasolla (341), erotettiin tutkimuksessa massateollisuus ja paperiteollisuus omiksi toimialoiksi. On selvää, että toimialaerotuksella ei voida kuitenkaan välttää aineistoon mahdollisesti sisältyviä muita aggregointi- tai mittausvirheitä, jotka ovat tyypillisiä aikasarja-aineistoa käyttäville toimialatutkimuksille.

Malli saadaan estimoitavaan muotoon approksimoimalla ns. joustavamuotoisella translogfunktiolla panoskysyntäfunktioita. Panoskysynnät estimoidaan systeeminä käyttäen Englen ja Grangerin (1987) esittämää kaksivaiheista menettelyä. Ensin estimoidaan tasoregressio (ns. yhteisintegroituvuusregressio) käyttäen Zellnerin iteratiivista menetelmää. Siinä kustannusosuuksien arvoja selitetään panoshintojen saman periodin arvoilla ja aikatrendillä. Yhtälöt eivät sisällä dynamiikkaa ja ne voidaan tulkita eräänlaisiksi pitkän aikavälin tasapainorelaatioiksi. Jos kyseessä on yhteisintegroitunut systeemi, tasoyhtälöiden virhetermit mittaavat sitä, kuinka paljon tasapainosta on poikettu. Estimointimenettelyn toisessa vaiheessa muodostetaan lyhyen aikavälin dynaaminen differenssiyhtälösysteemi. Tähän ns. virheenkorjausyhtälösysteemiin liitetään pitkän aikavälin yhtälöiden yhdellä periodilla viivästetyt virhetermit. Viivästettyjen residuaalien, ns. virheenkorjaustermien, tulee olla merkitsevästi negatiivisia. Zellnerin iteratiivisella estimointimenetelmällä saatuja tuloksia verrataan myös pienimmän neliösumman menetelmällä saatuihin tuloksiin.

Estimoiduista parametriarvoista lasketaan panosten kysynnän pitkän ja lyhyen aikavälin hintajoustot sekä Allenin osittaiset substituutiojoustot.

Tutkimuksen tulokset

Tutkimuksen empiiriset tulokset osoittavat, että käytetty virheenkorjausmalli soveltuu massa- ja paperiteollisuuden tuotantoteknologian ja sen muutoksien kuvaamiseen. Virheenkorjausestimaattien absoluuttiset arvot (0.5—0.8) osoittavat, että sopeutuminen lyhyen aikavälin epätasapainoilmiöihin on melko nopeaa massa- ja paperiteollisuudessa. Laskettujen joustoestimaattien merkittävimpänä tuloksena voidaan pitää sitä, että massa- ja paperiteollisuudessa tuotantopanoksien kysynnät reagoivat selvästi hintamuutoksiin ja tuotantopanosten välillä on merkittävää korvautuvuutta (substituutiota). Massateollisuuden osalta kaikki kysynnän oman hinnanjoustot ovat negatiivisia ja siten yhdenmukaisia kustannusten minimointioletuksen kanssa. Tulosten mukaan sähköenergia on kysynnän oman hinnan suhteen hyvin joustavaa muiden panosten oman hintajoustojen ollessa itseisarvoltaan ykköstä pienempiä. Ristijoustot osoittavat, että panokset ovat tyypillisemmin toisiaan korvaavia kuin toisiaan täydentäviä (komplementteja). Ainoastaan pääoma ja työvoima sekä raakapuu ja sähköenergia ovat komplementteja kaikkien muiden panosparien ollessa substituutteja. Odotetusti substituutiojoustot ovat pienempiä lyhyellä aikavälillä kuin pitkällä aikavälillä. Joustojen absoluuttiset arvot ovat keskimäärin hieman suurempia kuin aikaisemmissa koti- ja ulkomaisissa tutkimuksissa saadut. Paperiteollisuutta koskevat tulokset osoittavat, että pitkän aikavälin joustot oman hinnan suhteen ovat negatiivisia massan ja työvoiman osalta, mutta positiivisia pääoman ja sähköenergian osalta. Pääoman ja energiapanoksen oman hinnanjoustojen positiivisuus voi olla seurausta aineistossa olevista puutteista ja/tai siitä, että estimoinnissa käytetty translogfunktio on ainoastaan lokaalisesti hyvin käyttäytyvä eikä välttämättä täytä teorian asettamia ehtoja jokaisessa havaintopisteessä. Tulosten mukaan paperiteollisuudessa kaikki tuotantopanokset ovat substituutteja, korvautuvuuden ollessa kuitenkin hyvin heikkoa pääoman ja työn sekä massan ja sähköenergian välillä. Lyhyen aikavälin substituutiojoustot ovat pääosin pienempiä kuin vastaavat pitkän aikavälin joustot.

Tutkimusmetodi poikkeaa keskeisesti aikaisemmista panoskysyntätutkimuksista ottamalla huomioon muuttujien aikasarjaominaisuudet ja soveltamalla Englen ja Grangerin (1987) virheenkorjausmalli lähestymistapaa. Lähestymistapaa ja tutkimuksessa käytettävää epästationaaristen aikasarjojen ekonometriaa on kirjallisuudessa tutkittu vielä suhteellisen vähän. Esimerkiksi estimointimenettelyä ja tilastollisia testejä koskevat tulokset perustuvat jakaumien asymptoottisiin ominaisuuksiin ja simuloimalla saatuihin tuloksiin pienten otosten tilastollisten ominaisuuksien ollessa vielä selvittämättä. Näin ollen tutkimustulosten perusteella tehtävien johtopäätösten yhteydessä on huomioitava tutkimusmetodin ja testien vakiintumattomuus ja mahdolliset pienotosharhat. Toisaalta muuttujien aikasarjaominaisuudet huomioon ottava panoskysyntätutkimus on tilastoteoreettisesti vankemmalla perustalla kuin aikaisemmat tutkimukset, joissa näitä ominaisuuksia ei ole tarkasteltu.

APPENDIX A1: The aggregate data used in the *pulp industry* estimations

Data definitions:

NPU = labour input, quantity index of hours worked

RWQ = roundwood input, quantity of roundwood in million cubic meters

NQEPUL = electricity input, quantity of electricity in mega watt hours

CSPUL = net capital stock in 1985 prices

IPUL = gross fixed capital formation in 1985 prices

LWPUL = wage costs + social security charges for a unit of labour input

RWP = roundwood stumpage price index, weighted average (by cost shares) of the pine, spruce, non-coniferous pulpwood and wood chips and particles prices.

PIE = implicit price index of electricity

LPE85 = IVO tariff index of electricity

LUC85 = user cost of capital

obs	NPU	RWQ	NQEPUL	CSPUL	IPUL
1960	2518.246	70.36145	472929.6	7249.246	1604.783
1961	2664.498	80.87528	560664.3	7910.892	1843.670
1962	2633.446	82.87563	590956.0	9548.686	1662.285
1963	2577.925	92.26462	632584.8	9919.049	1063.671
1964	2510.759	99.22316	713430.1	10582.06	1366.646
1965	2496.203	104.0179	738408.6	10984.78	1104.666
1966	2312.729	103.0596	765176.5	10802.43	998.8029
1967	2207.441	103.8358	786465.3	10903.25	663.4491
1968	2354.803	105.0883	773503.9	10317.66	802.6011
1969	2125.721	113.4400	707701.4	10549.45	995.2131
1970	2216.315	116.3869	753629.7	10746.51	1301.082
1971	2211.184	109.0280	783226.5	13595.21	2040.890
1972	2176.250	115.7297	825306.4	11028.89	1200.148
1973	2105.065	121.1364	916673.0	10911.77	831.7421
1974	2071.726	118.5436	905990.3	10035.09	849.8015
1975	2066.873	96.40360	780848.5	10526.37	1348.772
1976	1997.281	86.85518	756680.6	11328.42	1513.633
1977	1841.256	88.59572	750867.7	12052.75	1648.276
1978	1761.476	106.6946	877950.0	11541.42	603.2712
1979	1769.516	124.5380	986797.1	11336.79	819.9497
1980	1768.199	130.6543	1034093.	11420.94	1192.790
1981	1700.826	126.1701	1113471.	11549.77	1355.521
1982	1512.846	109.1315	1034988.	11411.42	1307.741
1983	1390.507	117.5382	1165341.	11355.66	1023.978
1984	1336.234	132.1731	1304354.	11197.63	1152.544
1985	1181.803	129.0952	1113099.	11501.57	1372.605
1986	1041.234	129.7305	1269585.	11730.82	1310.740

obs	LWPUL	RWP	PIE	LPE85	LUC85
1960	0.249625	0.472069	0.611324	0.701732	0.165311
1961	0.269375	0.553775	0.578468	0.731291	0.167885
1962	0.286658	0.562548	0.573953	0.738434	0.170265
1963	0.319288	0.521079	0.574201	0.724316	0.181174
1964	0.353566	0.587383	0.570206	0.714293	0.196097
1965	0.380360	0.617079	0.567608	0.725644	0.209274
1966	0.400812	0.603310	0.572639	0.718914	0.205744
1967	0.423239	0.562514	0.568855	0.717999	0.211753
1968	0.421988	0.529176	0.579316	0.715691	0.234081
1969	0.471648	0.574146	0.624351	0.704704	0.245982
1970	0.494739	0.618368	0.633438	0.707631	0.269542
1971	0.526045	0.677175	0.652587	0.720732	0.298530
1972	0.561703	0.687604	0.681068	0.751201	0.335802
1973	0.609858	0.696573	0.690619	0.762081	0.421138
1974	0.664615	0.764880	0.789574	0.853969	0.510755
1975	0.717798	0.927525	0.822025	0.880539	0.580096
1976	0.758695	0.891606	0.847943	0.891449	0.633602
1977	0.785641	0.908876	0.868774	0.914069	0.683576
1978	0.806803	0.841361	0.861123	0.924375	0.687773
1979	0.830914	0.847189	0.881266	0.930698	0.712208
1980	0.873628	0.891791	0.913383	0.963787	0.771314
1981	0.907372	0.950972	0.945470	1.012789	0.828803
1982	0.932599	0.985872	0.970516	1.015540	0.898592
1983	0.951666	0.985110	0.946271	0.992118	0.903352
1984	0.977444	0.980695	0.958161	0.987206	0.951706
1985	1.000000	1.000000	1.000000	1.000000	1.000000
1986	1.020758	1.009644	0.953101	1.002000	1.014047

APPENDIX A2: The aggregate data used in the *paper industry* estimations

Data definitions:

NPA = labour input, hours worked

QPULP = pulp input, quantity in 1000 million tons

NQEPAP = electricity input in mega watt hours

CSPAP = net capital stock in 1985 prices

IPAP = gross fixed capital formation in 1985 prices

LWPAP = wage costs + social security charges for a unit labour input

PIP85 = implicit price index of pulp input

PIE = implicit price index of electricity

LUC85 = user cost of capital

obs	NPA	QPULP	NQEPAP	CSPAP	IPAP
1960	2455.289	3515.000	1213.425	6740.754	1492.217
1961	2712.890	4065.000	1451.593	8952.108	2086.330
1962	2758.703	4211.000	1581.920	9390.315	1634.715
1963	2757.587	4581.000	1709.252	9803.952	1051.329
1964	2861.743	5092.000	1821.296	10424.94	1346.354
1965	2855.268	5344.000	1926.727	10673.22	1073.334
1966	2902.192	5498.000	2213.043	11282.57	1043.197
1967	2766.292	5509.000	2194.881	10822.75	658.5508
1968	2877.130	5704.000	2453.243	11356.34	883.3990
1969	2966.524	6062.000	2707.130	11403.55	1075.787
1970	2940.764	6222.000	2924.683	12091.49	1463.919
1971	3101.592	5911.000	3443.192	10918.79	1639.110
1972	2956.708	6284.000	3951.193	14077.11	1531.851
1973	2993.955	6678.000	3855.689	13857.23	1056.258
1974	3136.889	6591.000	3785.214	14538.91	1231.198
1975	2994.721	5188.000	3059.908	14970.63	1918.228
1976	2995.209	5394.000	3517.368	15300.58	2044.368
1977	2824.703	5247.000	3546.097	15924.25	2177.724
1978	2794.420	6088.000	3925.416	15395.58	804.7286
1979	2839.396	7050.000	4205.006	15154.21	1096.050
1980	2938.049	7246.000	4546.256	15523.06	1621.210
1981	2933.244	7344.000	4808.566	16244.23	1906.479
1982	2833.893	6714.000	4839.089	17192.58	1970.259
1983	2687.687	7163.000	5197.584	17311.34	1561.022
1984	2716.443	8031.000	5871.018	17871.37	1839.455
1985	2651.554	7976.000	5819.379	18471.44	2204.395
1986	2598.015	7928.000	6206.029	18913.18	2113.260

obs	LWPAP	PIP85	PIE	LUC85
1960	0.232301	0.770964	0.611324	0.165311
1961	0.253492	0.775122	0.578468	0.167885
1962	0.268992	0.767013	0.573953	0.170265
1963	0.300066	0.771856	0.574201	0.181174
1964	0.335031	0.784425	0.570206	0.196097
1965	0.357035	0.788450	0.567608	0.209274
1966	0.384826	0.782709	0.572639	0.205744
1967	0.412772	0.785159	0.568855	0.211753
1968	0.439879	0.797271	0.579316	0.234081
1969	0.459739	0.813066	0.624351	0.245982
1970	0.494605	0.830952	0.633438	0.269542
1971	0.530134	0.844673	0.652587	0.298530
1972	0.571414	0.839701	0.681068	0.335802
1973	0.622626	0.848598	0.690619	0.421138
1974	0.673571	0.900129	0.789574	0.510755
1975	0.735077	0.950653	0.822025	0.580096
1976	0.765431	0.947415	0.847943	0.633602
1977	0.787635	0.942987	0.868774	0.683576
1978	0.805878	0.933896	0.861123	0.687773
1979	0.836526	0.952438	0.881266	0.712208
1980	0.873969	0.976238	0.913383	0.771314
1981	0.906217	0.996597	0.945470	0.828803
1982	0.932547	0.999935	0.970516	0.898592
1983	0.953317	1.002009	0.946271	0.903352
1984	0.976597	1.016506	0.958161	0.951706
1985	1.000000	1.000000	1.000000	1.000000
1986	1.013399	0.999333	0.953101	1.014047

APPENDIX B1: Autoregressive (AR) processes of the *pulp industry* series (t-values are given in brackets)

series	constant	AR(1)	AR(2)	AR(3)	AR(4)	$\overline{R}^2$
$\ln P_M$	1.7 (1.7)	1.0 (4.7)	-0.1 (-0.4)	-0.2 (-0.7)	0.3 (1.5)	0.93
$\ln P_K$	6.9 (0.6)	1.5 (6.3)	-0.6 (-1.3)	0.1 (0.2)	-0.1 (-0.3)	0.99
$\ln P_L$	4.9 (0.8)	1.3 (5.5)	-0.1 (-0.2)	-0.4 (-1.0	0.2 (0.7)	0.99
$\ln P_E$	1.0 (3.3)	1.0 (3.9)	-0.0 (-0.0)	0.3 (0.9)	-0.4 (-1.5)	0.97
S_M	0.2 (27.2)	1.0 (4.3)	-0.5 (-1.6)	0.3 (1.0)	-0.1 (-0.5)	0.58
S_K	-0.5 (-0.4)	0.9 (3.8)	0.0 (0.0)	-0.1 (-0.4)	0.3 (1.2)	0.93
S_E	0.2 (0.5)	0.9 (3.7)	0.1 (0.3)	-0.2 (-0.4)	0.2 (0.6)	0.74
S_L	0.4 (0.2)	1.0 (3.5)	-0.1 (-0.2)	0.0 (0.1)	0.3 (0.9)	0.96

Autoregressive processes of the *pulp industry* residuals

residual	constant	AR(1)	AR(2)	AR(3)	AR(4)	$\overline{R}^2$
ε_M	-0.0 (-0.6)	0.7 (3.0)	-0.4 (-1.2)	0.1 (0.3)	-0.1 (-0.4)	0.35
ε_K	0 .0 (0.4)	0.3 (1.3)	-0.0 (-0.0)	-0.4 (-1.6)	-0.0 (-0.1)	0.24
ε_E	-0.0 (-0.4)	0.4 (1.7)	0.1 (0.6)	-0.1 (-0.2)	-0.3 (-1.2)	0.29
ε_L	-0.0 (-0.2)	0.6 (2.5)	0.1 (0.3)	-0.1 (-0.3)	-0.1 (-0.5)	0.34

APPENDIX B2: Autoregressive (AR) processes of the *paper industry* series (t-values are given in brackets)

series	constant	AR(1)	AR(2)	AR(3)	AR(4)	$\overline{R}^2$
$\ln P_M$	-3.9 (-2.2)	1.0 (4.3)	-0.2 (-0.6)	0.0 (0.0)	0.1 (0.5)	0.88
$\ln P_K$	6.9 (0.6)	1.5 (6.3)	-0.6 (-1.3)	0.1 (0.2)	-0.1 (-0.3)	0.99
$\ln P_L$	2.33 (1.2)	1.7 (7.0)	-0.8 (-1.7)	-0.0 (-0.0)	0.1 (0.3)	0.99
$\ln P_E$	1.0 (3.3)	1.0 (3.9)	-0.0 (-0.0)	0.3 (0.9)	-0.4 (-1.5)	0.97
S_M	0.2 (1.4)	1.0 (4.3)	-0.2 (-0.5)	0.1 (0.2)	0.1 (0.3)	0.90
S_K	-0.6 (-0.8)	1.1 (4.8)	0.1 (0.2)	-0.3 (-0.8)	0.1 (0.4)	0.95
S_E	0.2 (4.6)	0.9 (4.0)	0.1 (0.2)	-0.2 (-0.5)	0.1 (0.3)	0.77
S_L	0.4 (1.2)	0.9 (4.2)	0.2 (0.6)	-0.3 (-1.0)	0.3 (1.3)	0.93

Autoregressive processes of the *paper industry* residuals

residual	constant	AR(1)	AR(2)	AR(3)	AR(4)	$\overline{R}^2$
ε_M	-0.0 (-0.1)	0.51 (2.3)	-0.3 (-1.1)	-0.2 (-0.6)	0.3 (1.3)	0.31
ε_K	0.0 (0.1)	0.7 (2.8)	-0.2 (-0.8)	-0.1 (-0.4)	0.1 (0.4)	0.33
ε_E	-0.0 (-0.4)	0.8 (3.6)	-0.8 (-3.0)	0.5 (2.0)	-0.6 (2.7)	0.53
ε_L	0.0 (0.6)	0.2 (0.9)	-0.1 (-0.4)	-0.0 (-0.1)	-0.4 (-1.8)	0.22

APPENDIX C1: Actual and fitted values of the *pulp industry long run* equations.

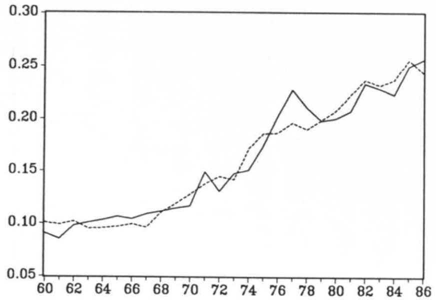

Figure 17. Capital cost share. — SK ----- SKFIT

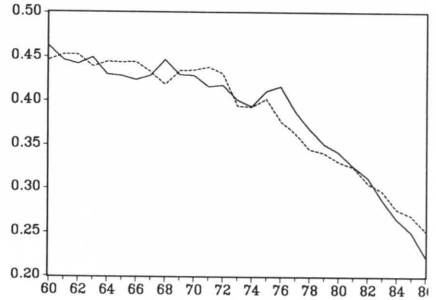

Figure 18. Labour cost share. — SL ----- SLFIT

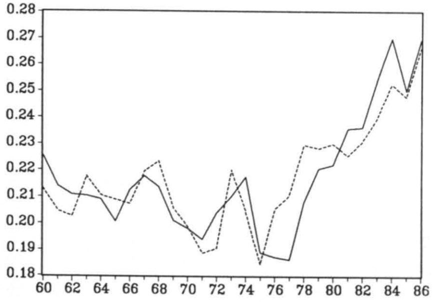

Figure 19. Elactricity cost share. — SE ----- SEFIT

Figure 20. Roundwood cost share. — SR ----- SRFIT

APPENDIX C2: Actual and fitted values of the *pulp industry short run* equations

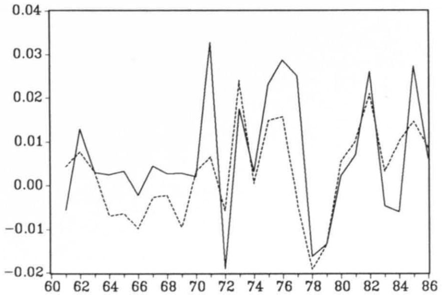

Figure 21. Capital cost share. — DSK ----- DSKFIT

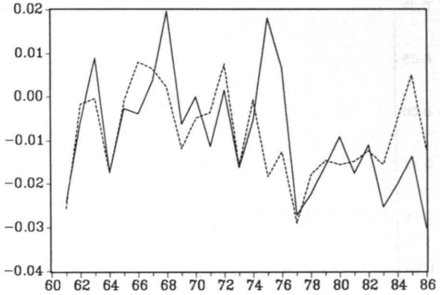

Figure 22. Labour cost share. — DSL ----- DSLFIT

Figure 23. ELECTRICITY SHARE

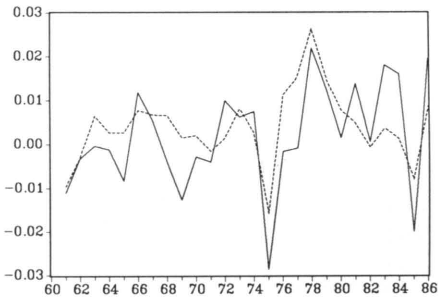

Figure 23. Electricity cost share. — DSE ----- DSEFIT

Figure 24. ROUNDWOOD SHARE

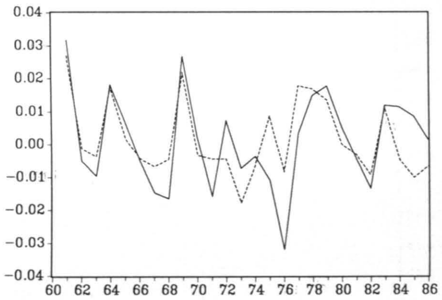

Figure 24. Roundwood cost share. — DSR ----- DSRFIT

APPENDIX C3: Actual and fitted values of the *paper industry long run* equations

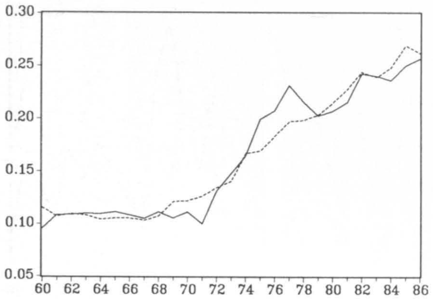

Figure 25. Capital cost share. —— SK ----- SKFIT

Figure 26. Labour cost share. —— SL ----- SLFIT

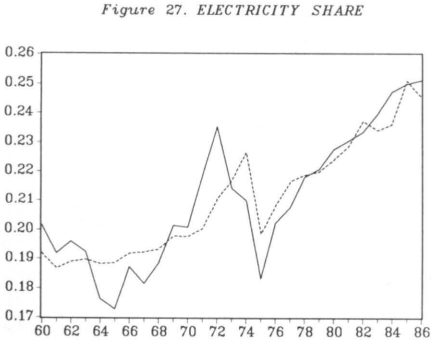

Figure 27. Electricity cost share. —— SE ----- SEFIT

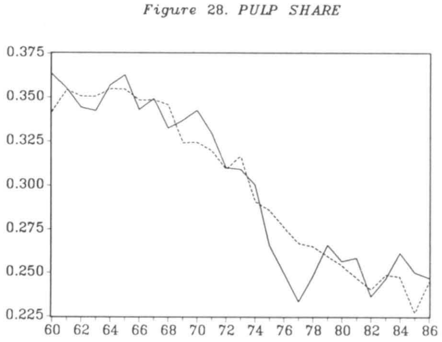

Figure 28. Pulp cost share.

APPENDIX C4: Actual and fitted values of the *paper industry short run* equations

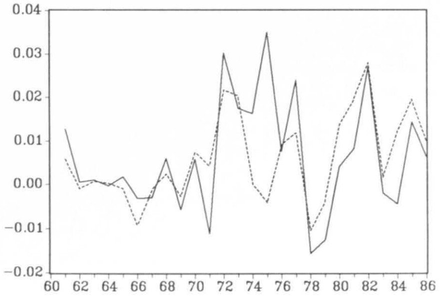

Figure 29. Capital cost share. —— DSK ----- DSKFIT

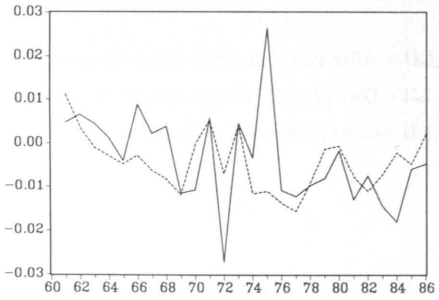

Figure 30. Labour cost share. —— DSL ----- DSLFIT

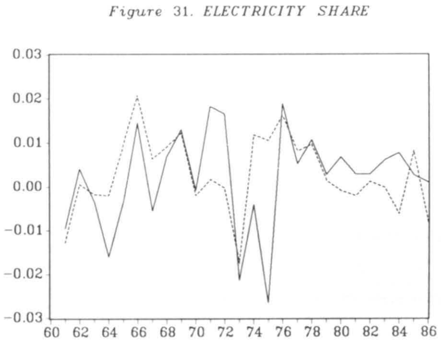

Figure 31. Electricity cost share. —— DSE ----- DSEFIT

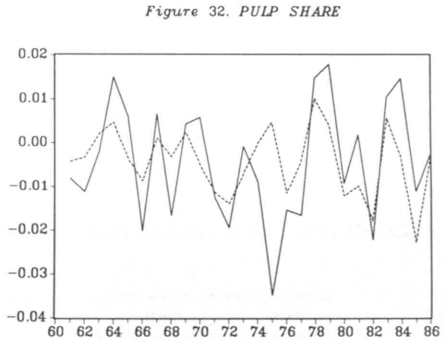

Figure 32. Pulp cost share. —— DSP ----- DSPFIT

APPENDIX D: Estimated elasticities from the pulp and paper industry models

Definitions of symbols:

OIJ = Allen partial elasticity of substitution.
EII = Own price (or direct) elasticity of demand.
EIJ = Cross price elasticity of demand.

K = capital
L = labour
E = electricity
R = roundwood
P = pulp

APPENDIX D1: Estimated *long run* elasticities from the *pulp industry* model

obs	ORR	OKK	OLL	OEE
1960	-4.623211	-4.596580	-1.271143	-9.075818
1961	-3.940061	-4.528703	-1.402527	-8.705722
1962	-4.079625	-4.593603	-1.436035	-8.733294
1963	-4.288580	-4.575794	-1.384218	-8.994249
1964	-3.846651	-4.554900	-1.487832	-9.174848
1965	-3.720922	-4.525662	-1.504469	-9.568645
1966	-3.816822	-4.546135	-1.528814	-8.899614
1967	-4.172368	-4.501463	-1.505612	-8.475683
1968	-4.570223	-4.458572	-1.387779	-9.005295
1969	-3.763155	-4.379827	-1.424062	-11.30995
1970	-3.706479	-4.342315	-1.423964	-11.77060
1971	-4.050380	-3.753801	-1.492102	-12.40397
1972	-3.883105	-4.100443	-1.482706	-11.39388
1973	-4.062441	-3.784009	-1.587361	-10.80799
1974	-4.131466	-3.715756	-1.623135	-10.45691
1975	-4.395369	-3.313672	-1.504327	-13.57871
1976	-5.433148	-2.876505	-1.463590	-14.17404
1977	-5.302313	-2.559951	-1.640306	-14.28660
1978	-4.823064	-2.774912	-1.805506	-11.42852
1979	-4.282618	-2.945076	-1.935789	-10.54900
1980	-4.139773	-2.913556	-2.015683	-10.43738
1981	-4.282317	-2.829672	-2.185259	-9.202851
1982	-4.629153	-2.494695	-2.300585	-9.461447
1983	-4.296806	-2.551133	-2.601987	-8.297090
1984	-3.982185	-2.610741	-2.882631	-7.623804
1985	-3.740155	-2.285600	-3.098921	-9.090000
1986	-3.784265	-2.256952	-3.676897	-7.457010

obs	OKE	OKL	OKR	OLE
1960	16.76680	-11.14557	5.473922	3.480448
1961	17.77335	-12.98087	5.360951	3.561305
1962	15.63536	-11.34457	4.890468	3.601127
1963	15.36971	-10.67174	4.889318	3.589035
1964	15.15318	-10.85495	4.514511	3.730219
1965	15.08308	-10.59677	4.338767	3.813891
1966	14.78466	-10.93612	4.463561	3.727454
1967	13.89517	-10.37233	4.540521	3.629751
1968	13.93619	-9.515590	4.657272	3.594636
1969	15.01530	-9.172523	4.047812	3.993573
1970	15.04318	-8.965907	3.955268	4.061469
1971	12.25380	-6.969042	3.443650	4.240439
1972	13.30977	-8.109605	3.723673	4.077711
1973	11.53381	-7.363742	3.476720	4.111638
1974	11.07818	-7.263019	3.442269	4.095933
1975	11.08706	-5.821148	3.202818	4.426141
1976	9.835046	-4.738591	3.185581	4.453551
1977	8.901628	-4.470343	2.912752	4.713893
1978	8.543816	-5.285772	2.936874	4.477199
1979	8.669651	-5.990296	2.896039	4.475680
1980	8.537799	-6.096124	2.831115	4.547298
1981	7.812833	-6.263968	2.818523	4.487266
1982	7.115225	-5.647354	2.696647	4.667779
1983	6.802011	-6.396576	2.645314	4.711656
1984	6.657472	-7.138519	2.596124	4.809387
1985	6.519632	-6.585648	2.351610	5.433024
1986	5.884747	-7.530883	2.347343	5.511649

obs	OLR	ORE
1960	3.108249	-3.468538
1961	2.994666	-2.907272
1962	3.071129	-3.009151
1963	3.098992	-3.219307
1964	3.030746	-2.958473
1965	2.998218	-2.962063
1966	3.052729	-2.870635
1967	3.162731	-3.004033
1968	3.197226	-3.413320
1969	2.949948	-3.386464
1970	2.929785	-3.439920
1971	3.107613	-3.859615
1972	3.039767	-3.500372
1973	3.191431	-3.506408
1974	3.247244	-3.475189
1975	3.241128	-4.411174
1976	3.559006	-5.432690
1977	3.692893	-5.350951
1978	3.674158	-4.240073
1979	3.573705	-3.610591
1980	3.581167	-3.476693
1981	3.788196	-3.269676
1982	4.048101	-3.578369
1983	4.152721	-3.037858
1984	4.219190	-2.653771
1985	4.251536	-2.862992
1986	4.727509	-2.484854

obs	EER	EEK	EEL	EEE
1960	-0.748965	1.466169	0.501620	-2.270946
1961	-0.701355	1.427160	0.471740	-2.229873
1962	-0.708743	1.441447	0.464682	-2.232967
1963	-0.732486	1.467211	0.475688	-2.261978
1964	-0.725552	1.485166	0.454180	-2.281770
1965	-0.743121	1.521164	0.450908	-2.324156
1966	-0.707772	1.462548	0.446203	-2.251515
1967	-0.696636	1.429659	0.450685	-2.203826
1968	-0.743000	1.478808	0.474915	-2.263196
1969	-0.843075	1.671719	0.467180	-2.500505
1970	-0.865297	1.709476	0.467201	-2.544533
1971	-0.913574	1.789656	0.453336	-2.603520
1972	-0.852919	1.694179	0.455198	-2.508600
1973	-0.828269	1.665419	0.435284	-2.451358
1974	-0.811404	1.641168	0.428872	-2.416210
1975	-0.986669	1.900891	0.450936	-2.708639
1976	-1.047152	1.972203	0.459035	-2.759992
1977	-1.049327	2.004785	0.425862	-2.769568
1978	-0.888832	1.777628	0.398935	-2.511932
1979	-0.822308	1.696036	0.380003	-2.425494
1980	-0.810629	1.689317	0.369264	-2.414236
1981	-0.744701	1.593490	0.348386	-2.284819
1982	-0.771988	1.642134	0.335500	-2.312719
1983	-0.690283	1.536970	0.305972	-2.183317
1984	-0.635537	1.471302	0.282851	-2.103558
1985	-0.715744	1.629936	0.267317	-2.272500
1986	-0.616255	1.487737	0.233220	-2.083156

obs	EKL	EKE	EKR	ELK
1960	-4.975440	4.195379	1.181996	-0.974603
1961	-5.482104	4.552443	1.293292	-1.042315
1962	-4.726095	3.997718	1.151854	-1.045852
1963	-4.541024	3.865353	1.112468	-1.018718
1964	-4.429325	3.768572	1.107169	-1.063876
1965	-4.295675	3.663573	1.088514	-1.068689
1966	-4.391192	3.740374	1.100524	-1.081817
1967	-4.202803	3.612988	1.052954	-1.067178
1968	-4.043108	3.502420	1.013785	-1.009707
1969	-3.839831	3.319716	1.007726	-1.021197
1970	-3.753487	3.251990	0.994936	-1.018848
1971	-2.838894	2.572001	0.815118	-1.017803
1972	-3.315829	2.930423	0.907334	-1.032239
1973	-2.890865	2.615981	0.821261	-1.063265
1974	-2.813031	2.559763	0.803722	-1.075955
1975	-2.359885	2.211612	0.716394	-0.998025
1976	-1.952313	1.915096	0.614025	-0.950203
1977	-1.720317	1.725649	0.571196	-1.006773
1978	-1.916202	1.877888	0.615650	-1.099739
1979	-2.076824	1.993382	0.659573	-1.171855
1980	-2.058486	1.974850	0.660109	-1.206177
1981	-2.004542	1.939715	0.641950	-1.277564
1982	-1.745246	1.739218	0.581771	-1.303339
1983	-1.814550	1.789898	0.601089	-1.445334
1984	-1.881700	1.836928	0.621735	-1.577586
1985	-1.646412	1.629908	0.587902	-1.646412
1986	-1.655517	1.643936	0.582155	-1.903868

obs	ELR	ELE	EEK	EEL
1960	0.671171	0.870876	1.466169	0.501620
1961	0.722443	0.912188	1.427160	0.471740
1962	0.723345	0.920752	1.441447	0.464682
1963	0.705115	0.902612	1.467211	0.475688
1964	0.743280	0.927700	1.485166	0.454180
1965	0.752196	0.926367	1.521164	0.450908
1966	0.752673	0.943009	1.462548	0.446203
1967	0.733442	0.943799	1.429659	0.450685
1968	0.695966	0.903398	1.478808	0.474915
1969	0.734407	0.882935	1.671719	0.467180
1970	0.736979	0.877996	1.709476	0.467201
1971	0.735578	0.890043	1.789656	0.453336
1972	0.740689	0.897793	1.694179	0.455198
1973	0.753871	0.932560	1.665419	0.435284
1974	0.758186	0.946421	1.641168	0.428872
1975	0.724963	0.882913	1.900891	0.450936
1976	0.686003	0.867203	1.972203	0.459035
1977	0.724184	0.913824	2.004785	0.425862
1978	0.770205	0.984066	1.777628	0.398935
1979	0.813911	1.029077	1.696036	0.380003
1980	0.834993	1.051821	1.689317	0.369264
1981	0.862804	1.114066	1.593490	0.348386
1982	0.873331	1.140974	1.642134	0.335500
1983	0.943614	1.239837	1.536970	0.305972
1984	1.010436	1.327005	1.471302	0.282851
1985	1.062884	1.358256	1.629936	0.267317
1986	1.172451	1.539709	1.487737	0.233220

obs	EER	ERK	ERL	ERE
1960	-0.748965	0.478657	1.387538	-0.867895
1961	-0.701355	0.430464	1.264713	-0.744665
1962	-0.708743	0.450851	1.279418	-0.769393
1963	-0.732486	0.466731	1.318679	-0.809629
1964	-0.725552	0.442460	1.236685	-0.735767
1965	-0.743121	0.437566	1.215405	-0.719464
1966	-0.707772	0.441542	1.225765	-0.726242
1967	-0.696636	0.467161	1.281519	-0.781101
1968	-0.743000	0.494187	1.358479	-0.857830
1969	-0.843075	0.450652	1.234917	-0.748710
1970	-0.865297	0.449460	1.226525	-0.743632
1971	-0.913574	0.502932	1.265911	-0.810111
1972	-0.852919	0.473971	1.242890	-0.770680
1973	-0.828269	0.502010	1.252895	-0.795288
1974	-0.811404	0.509943	1.257686	-0.802989
1975	-0.986669	0.549117	1.313949	-0.879927
1976	-1.047152	0.638787	1.466320	-1.057862
1977	-1.049327	0.655985	1.421132	-1.037323
1978	-0.888832	0.611036	1.331958	-0.931947
1979	-0.822308	0.566539	1.238997	-0.830170
1980	-0.810629	0.560164	1.209257	-0.804182
1981	-0.744701	0.574850	1.212267	-0.811772
1982	-0.771988	0.622352	1.251016	-0.874683
1983	-0.690283	0.597720	1.178024	-0.799389
1984	-0.635537	0.573734	1.112171	-0.732228
1985	-0.715744	0.587902	1.062884	-0.715748
1986	-0.616255	0.593427	1.039250	-0.694157

APPENDIX D2: Estimated *"intermediate"* elasticities from the *pulp industry* model

obs	ORR	OKK	OLL	OEE
1960	-4.253044	-6.407915	-1.258008	-6.276493
1961	-3.643493	-6.676828	-1.387851	-6.034287
1962	-3.768497	-6.223218	-1.420953	-6.052356
1963	-3.955189	-6.095686	-1.369762	-6.223175
1964	-3.559688	-5.996760	-1.472112	-6.341178
1965	-3.446703	-5.887404	-1.488541	-6.597899
1966	-3.532901	-5.961502	-1.512579	-6.161271
1967	-3.851426	-5.809828	-1.489670	-5.883355
1968	-4.205969	-5.688645	-1.373280	-6.230397
1969	-3.484678	-5.497225	-1.409126	-7.724351
1970	-3.433710	-5.414870	-1.409029	-8.020211
1971	-3.742324	-4.403136	-1.476328	-8.425695
1972	-3.592407	-4.955290	-1.467049	-7.778323
1973	-3.753119	-4.448309	-1.570377	-7.400995
1974	-3.814866	-4.346853	-1.605686	-7.174203
1975	-4.050389	-3.784849	-1.488400	-9.174074
1976	-4.968591	-3.220946	-1.448170	-9.551649
1977	-4.853497	-2.833018	-1.622631	-9.622913
1978	-4.430296	-3.094866	-1.785589	-7.800588
1979	-3.949869	-3.306984	-1.914012	-7.233745
1980	-3.822293	-3.267338	-1.992726	-7.161569
1981	-3.949601	-3.162626	-2.159699	-6.359460
1982	-4.258320	-2.754726	-2.273178	-6.528093
1983	-3.962527	-2.822407	-2.569460	-5.765967
1984	-3.681249	-2.894323	-2.844960	-5.321674
1985	-3.464000	-2.507200	-3.057040	-6.285760
1986	-3.503652	-2.473657	-3.622732	-5.211158

obs	OKL	ORK	OKE	OLE
1960	-7.378624	3.828123	11.87982	2.425928
1961	-8.644703	3.756711	12.57438	2.472410
1962	-7.515902	3.459302	11.09907	2.495303
1963	-7.051751	3.458575	10.91576	2.488351
1964	-7.178140	3.221646	10.76634	2.569513
1965	-7.000035	3.110552	10.71797	2.617614
1966	-7.234133	3.189439	10.51205	2.567924
1967	-6.845205	3.238088	9.898260	2.511758
1968	-6.254180	3.311890	9.926566	2.491571
1969	-6.017515	2.926629	10.67120	2.720907
1970	-5.874982	2.868129	10.69044	2.759938
1971	-4.497444	2.544717	8.765641	2.862822
1972	-5.284262	2.721730	9.494305	2.769275
1973	-4.769728	2.565622	8.268813	2.788778
1974	-4.700244	2.543844	7.954408	2.779750
1975	-3.705570	2.392479	7.960535	2.969576
1976	-2.958768	2.381583	7.096588	2.985333
1977	-2.773717	2.209118	6.452487	3.134996
1978	-3.336241	2.224366	6.205580	2.998928
1979	-3.822256	2.198553	6.292412	2.998054
1980	-3.895262	2.157512	6.201428	3.039225
1981	-4.011049	2.149552	5.701168	3.004715
1982	-3.585678	2.072510	5.219787	3.108486
1983	-4.102529	2.040061	5.003655	3.133709
1984	-4.614358	2.008966	4.903916	3.189892
1985	-4.232960	1.854400	4.808800	3.548400
1986	-4.885031	1.851703	4.370700	3.593599

obs	ORL	ORE
1960	2.331006	0.718122
1961	2.259298	0.753527
1962	2.307571	0.747100
1963	2.325162	0.733844
1964	2.282076	0.750297
1965	2.261540	0.750071
1966	2.295954	0.755838
1967	2.365402	0.747423
1968	2.387180	0.721605
1969	2.231065	0.723299
1970	2.218336	0.719927
1971	2.330604	0.693452
1972	2.287771	0.716114
1973	2.383521	0.715733
1974	2.418758	0.717702
1975	2.414896	0.658660
1976	2.615583	0.594222
1977	2.700110	0.599378
1978	2.688283	0.669453
1979	2.624863	0.709161
1980	2.629574	0.717607
1981	2.760279	0.730666
1982	2.924365	0.711194
1983	2.990414	0.745289
1984	3.032379	0.769518
1985	3.052800	0.756320
1986	3.353297	0.780173

obs	EKK	ELL	EEE	ERR
1960	-0.560328	-0.561581	-1.570500	-0.918369
1961	-0.536124	-0.586120	-1.545614	-0.878968
1962	-0.573717	-0.591962	-1.547493	-0.887596
1963	-0.581890	-0.582859	-1.565076	-0.899925
1964	-0.587733	-0.600690	-1.577041	-0.873002
1965	-0.593747	-0.603419	-1.602583	-0.864712
1966	-0.589720	-0.607347	-1.558741	-0.871063
1967	-0.597756	-0.603605	-1.529775	-0.893151
1968	-0.603627	-0.583497	-1.565813	-0.915546
1969	-0.612018	-0.589893	-1.707768	-0.867531
1970	-0.615323	-0.589876	-1.733785	-0.863739
1971	-0.643062	-0.601394	-1.768504	-0.885815
1972	-0.630739	-0.599842	-1.712560	-0.875349
1973	-0.642300	-0.616500	-1.678618	-0.886551
1974	-0.643949	-0.621896	-1.657696	-0.890718
1975	-0.648906	-0.603395	-1.830016	-0.905976
1976	-0.645878	-0.596650	-1.859912	-0.957702
1977	-0.638028	-0.624435	-1.865476	-0.951780
1978	-0.643907	-0.647313	-1.714530	-0.928713
1979	-0.646931	-0.663584	-1.663229	-0.899583
1980	-0.646474	-0.672886	-1.656519	-0.891215
1981	-0.645032	-0.691129	-1.578882	-0.899566
1982	-0.635756	-0.702498	-1.595702	-0.918684
1983	-0.637735	-0.728892	-1.517271	-0.900397
1984	-0.639635	-0.749926	-1.468355	-0.881607
1985	-0.626800	-0.764260	-1.571440	-0.866000
1986	-0.625360	-0.796387	-1.455765	-0.868927

obs	EKL	EKE	EKR	ELK
1960	-3.293855	2.972561	0.826615	-0.645210
1961	-3.650847	3.220785	0.906281	-0.694137
1962	-3.131089	2.837859	0.814771	-0.692889
1963	-3.000651	2.745222	0.786931	-0.673156
1964	-2.929015	2.677572	0.790098	-0.703518
1965	-2.837645	2.603319	0.780378	-0.705956
1966	-2.904729	2.659445	0.786380	-0.715611
1967	-2.773634	2.573721	0.750917	-0.704283
1968	-2.657357	2.494728	0.720925	-0.663636
1969	-2.519072	2.359284	0.728601	-0.669943
1970	-2.459503	2.311027	0.721469	-0.667608
1971	-1.832069	1.839856	0.602339	-0.656835
1972	-2.160612	2.090369	0.663194	-0.672613
1973	-1.872505	1.875448	0.606044	-0.688710
1974	-1.820445	1.837973	0.593952	-0.696301
1975	-1.502233	1.587943	0.535141	-0.635313
1976	-1.219021	1.381859	0.459053	-0.593305
1977	-1.067406	1.250864	0.433212	-0.624673
1978	-1.209456	1.363956	0.466289	-0.694127
1979	-1.325169	1.446792	0.500721	-0.747731
1980	-1.315318	1.434432	0.503051	-0.770715
1981	-1.283582	1.415445	0.489584	-0.818071
1982	-1.108110	1.275904	0.447120	-0.827530
1983	-1.163786	1.316674	0.463559	-0.926984
1984	-1.216336	1.353087	0.481119	-1.019756
1985	-1.058240	1.202200	0.463600	-1.058240
1986	-1.073878	1.220979	0.459233	-1.234975

obs	ELE	ELR	EEK	EEL
1960	0.607014	0.503339	1.038808	1.082947
1961	0.633280	0.545040	1.009675	1.044153
1962	0.638010	0.543503	1.023220	1.039531
1963	0.625799	0.529045	1.042012	1.058840
1964	0.639034	0.559672	1.055192	1.048481
1965	0.635800	0.567377	1.080912	1.061118
1966	0.649660	0.566084	1.039867	1.031101
1967	0.653101	0.548540	1.018402	1.017748
1968	0.626177	0.519636	1.053316	1.058651
1969	0.601562	0.555437	1.188048	1.139035
1970	0.596635	0.558016	1.214817	1.155420
1971	0.600890	0.551659	1.280189	1.166193
1972	0.609713	0.557453	1.208492	1.132292
1973	0.632522	0.563029	1.193950	1.094821
1974	0.642299	0.564746	1.178378	1.076621
1975	0.592362	0.540155	1.364819	1.203862
1976	0.581309	0.504157	1.423039	1.229966
1977	0.607743	0.529497	1.453174	1.206437
1978	0.659149	0.563539	1.291111	1.087173
1979	0.689332	0.597812	1.230957	1.039420
1980	0.702993	0.613118	1.227013	1.026259
1981	0.745989	0.628684	1.162778	0.961544
1982	0.759826	0.630898	1.204662	0.960640
1983	0.824612	0.679506	1.130597	0.888955
1984	0.880154	0.726212	1.083747	0.840850
1985	0.887100	0.763200	1.202200	0.887100
1986	1.003891	0.831638	1.104948	0.789982

obs	EER	ERK	ERL	ERE
1960	0.155066	0.334743	1.040573	0.179688
1961	0.181783	0.301650	0.954151	0.193007
1962	0.175965	0.318912	0.961323	0.191022
1963	0.166972	0.330153	0.989400	0.184556
1964	0.184008	0.315748	0.931193	0.186598
1965	0.188178	0.313700	0.916774	0.182187
1966	0.186357	0.315504	0.921897	0.191220
1967	0.173329	0.333157	0.958446	0.194343
1968	0.157078	0.351427	1.014296	0.181352
1969	0.180070	0.325828	0.933976	0.159913
1970	0.181095	0.325922	0.928684	0.155632
1971	0.164142	0.371646	0.949390	0.145552
1972	0.174493	0.346438	0.935417	0.157667
1973	0.169068	0.370455	0.935725	0.162335
1974	0.167573	0.376849	0.936806	0.165835
1975	0.147326	0.410186	0.978996	0.131387
1976	0.114537	0.477565	1.077628	0.115708
1977	0.117539	0.497519	1.039080	0.116194
1978	0.140336	0.462794	0.974558	0.147142
1979	0.161511	0.430093	0.910035	0.163055
1980	0.167319	0.426885	0.887932	0.165987
1981	0.166417	0.438411	0.883321	0.181405
1982	0.153432	0.478309	0.903739	0.173841
1983	0.169351	0.460961	0.848306	0.196117
1984	0.184289	0.443974	0.799329	0.212325
1985	0.189080	0.463600	0.763200	0.189080
1986	0.193488	0.468125	0.737157	0.217946

APPENDIX D3: Estimated *long run* elasticities from the *paper industry* model

obs	OKK	OLL	OEE	OPP
1960	5.590807	-1.023148	0.307331	-1.901482
1961	3.470411	-1.007464	0.497664	-1.970572
1962	3.402511	-0.986113	0.411902	-2.072905
1963	3.277247	-0.971685	0.486004	-2.091355
1964	3.318453	-0.967458	0.904069	-1.954373
1965	3.102333	-0.980153	1.021937	-1.904296
1966	3.488337	-0.952195	0.604515	-2.085060
1967	3.913286	-0.945067	0.751620	-2.024816
1968	3.113364	-0.932929	0.575682	-2.186290
1969	3.864608	-0.969346	0.308221	-2.143726
1970	3.089867	-1.004276	0.321353	-2.088459
1971	4.703156	-0.985912	0.049825	-2.214088
1972	1.402387	-1.074385	-0.119414	-2.428558
1973	0.509573	-1.059386	0.111658	-2.437972
1974	-0.006823	-1.070281	0.171596	-2.546025
1975	-0.566327	-0.984534	0.705810	-3.043492
1976	-0.631311	-1.019982	0.296161	-3.313194
1977	-0.759291	-1.060196	0.209324	-3.647736
1978	-0.686539	-1.092534	0.060159	-3.350173
1979	-0.596344	-1.119283	0.026396	-3.037735
1980	-0.630060	-1.124871	-0.047660	-3.193998
1981	-0.686236	-1.167453	-0.076331	-3.162524
1982	-0.791395	-1.191494	-0.103161	-3.585748
1983	-0.786622	-1.236274	-0.153698	-3.377907
1984	-0.774630	-1.286982	-0.209046	-3.115059
1985	-0.806576	-1.301952	-0.226272	-3.312480
1986	-0.814962	-1.312931	-0.232929	-3.366152

obs	OKL	OKE	OKP	OLE
1960	-0.194731	1.159834	1.465956	1.024515
1961	-0.068040	1.134148	1.401612	1.023016
1962	-0.083346	1.136348	1.387031	1.023063
1963	-0.087371	1.132669	1.381370	1.022357
1964	-0.094709	1.121973	1.399342	1.020417
1965	-0.065309	1.117558	1.399437	1.020221
1966	-0.123009	1.131078	1.387935	1.021388
1967	-0.162975	1.130810	1.406790	1.020611
1968	-0.111264	1.128365	1.366101	1.021167
1969	-0.134862	1.144673	1.390929	1.023360
1970	-0.041695	1.136481	1.376417	1.024008
1971	-0.177430	1.165513	1.403034	1.025759
1972	0.165762	1.136684	1.291168	1.030023
1973	0.254411	1.109556	1.255948	1.026925
1974	0.335851	1.096635	1.223691	1.026662
1975	0.408333	1.069542	1.162959	1.021538
1976	0.448003	1.073868	1.147745	1.024521
1977	0.522932	1.067953	1.123582	1.026101
1978	0.503582	1.076649	1.140980	1.028293
1979	0.486319	1.082438	1.160496	1.029408
1980	0.499418	1.083271	1.151781	1.030482
1981	0.539152	1.081079	1.146936	1.032238
1982	0.600720	1.072989	1.119351	1.033497
1983	0.617566	1.075513	1.125659	1.036182
1984	0.635931	1.079412	1.135636	1.039969
1985	0.664936	1.075643	1.122332	1.041368
1986	0.679574	1.074050	1.117869	1.042347

obs	OLP	OEP
1960	1.200364	0.476572
1961	1.193181	0.462467
1962	1.183536	0.490345
1963	1.180183	0.483869
1964	1.187409	0.412155
1965	1.192627	0.389935
1966	1.177468	0.468615
1967	1.179698	0.441645
1968	1.169250	0.487923
1969	1.176970	0.514834
1970	1.185640	0.504803
1971	1.175853	0.562789
1972	1.179307	0.617521
1973	1.176358	0.580533
1974	1.173032	0.584380
1975	1.141496	0.579264
1976	1.137506	0.640880
1977	1.133082	0.673466
1978	1.145899	0.669757
1979	1.160515	0.650443
1980	1.155771	0.672732
1981	1.163800	0.674611
1982	1.153565	0.706404
1983	1.168803	0.701221
1984	1.191396	0.693332
1985	1.187567	0.709631
1986	1.188981	0.714204

obs	EKK	ELL	EEE	EPP
1960	0.533087	-0.347860	0.061920	-0.690590
1961	0.375425	-0.347401	0.095475	-0.699844
1962	0.369857	-0.346577	0.080706	-0.712883
1963	0.359480	-0.345892	0.093498	-0.715155
1964	0.362909	-0.345672	0.159424	-0.697708
1965	0.344753	-0.346307	0.176492	-0.690974
1966	0.376888	-0.344806	0.113178	-0.714382
1967	0.410822	-0.344364	0.136452	-0.706851
1968	0.345690	-0.343554	0.108471	-0.726483
1969	0.407006	-0.345772	0.062083	-0.721477
1970	0.343692	-0.347293	0.064493	-0.714800
1971	0.470471	-0.346568	0.010906	-0.729692
1972	0.182677	-0.348448	-0.028107	-0.752951
1973	0.075316	-0.348424	0.023902	-0.753916
1974	-0.001121	-0.348454	0.036006	-0.764682
1975	-0.112875	-0.346507	0.129330	-0.808056
1976	-0.130660	-0.347777	0.059857	-0.828171
1977	-0.175260	-0.348429	0.043404	-0.850576
1978	-0.147729	-0.348302	0.013117	-0.830776
1979	-0.120843	-0.347719	0.005829	-0.807603
1980	-0.130297	-0.347539	-0.010850	-0.819531
1981	-0.147629	-0.345436	-0.017601	-0.817185
1982	-0.191519	-0.343607	-0.024089	-0.846613
1983	-0.188781	-0.338638	-0.036822	-0.832708
1984	-0.182475	-0.329410	-0.051697	-0.813595
1985	-0.201644	-0.325488	-0.056568	-0.828120
1986	-0.209031	-0.322043	-0.058486	-0.831892

obs	EKL	EKE	EKP	ELK
1960	-0.066206	0.233677	0.532413	-0.018568
1961	-0.023462	0.217582	0.497779	-0.007361
1962	-0.029292	0.222651	0.477008	-0.009060
1963	-0.031102	0.217904	0.472370	-0.009584
1964	-0.033839	0.197850	0.499563	-0.010357
1965	-0.023075	0.193006	0.507786	-0.007258
1966	-0.044544	0.211761	0.475534	-0.013290
1967	-0.059385	0.205292	0.491102	-0.017109
1968	-0.040973	0.212609	0.453942	-0.012354
1969	-0.048106	0.230566	0.468121	-0.014203
1970	-0.014419	0.228083	0.471095	-0.004638
1971	-0.062370	0.255106	0.462395	-0.017749
1972	0.053760	0.267547	0.400314	0.021592
1973	0.083674	0.237518	0.388388	0.037603
1974	0.109344	0.230109	0.367528	0.055164
1975	0.143713	0.195978	0.308769	0.081386
1976	0.152753	0.217037	0.286892	0.092721
1977	0.171860	0.221444	0.261996	0.120704
1978	0.160543	0.234751	0.282940	0.108360
1979	0.151081	0.239047	0.308526	0.098547
1980	0.154300	0.246612	0.295529	0.103280
1981	0.159529	0.249282	0.296364	0.115987
1982	0.173237	0.250554	0.264284	0.145375
1983	0.169162	0.257668	0.277493	0.148209
1984	0.162770	0.266939	0.296607	0.149802
1985	0.166234	0.268911	0.280583	0.166234
1986	0.166690	0.269682	0.276264	0.174305

obs	ELE	ELP	EEK	EEL
1960	0.206414	0.435954	0.110591	0.348325
1961	0.196262	0.423755	0.122691	0.352764
1962	0.200454	0.407025	0.123522	0.359563
1963	0.196682	0.403573	0.124242	0.363930
1964	0.179942	0.423903	0.122700	0.364594
1965	0.176196	0.432745	0.124191	0.360463
1966	0.191225	0.403424	0.122204	0.369862
1967	0.185286	0.411825	0.118714	0.371890
1968	0.192411	0.388531	0.125287	0.376048
1969	0.206130	0.396112	0.120553	0.365039
1970	0.205510	0.405799	0.126413	0.354116
1971	0.224517	0.387523	0.116590	0.360575
1972	0.242442	0.365633	0.148066	0.334060
1973	0.219829	0.363776	0.163995	0.337748
1974	0.215427	0.352313	0.180124	0.334253
1975	0.187182	0.303070	0.213172	0.359531
1976	0.207064	0.284333	0.222254	0.349325
1977	0.212766	0.264211	0.246506	0.337224
1978	0.224208	0.284160	0.231673	0.327821
1979	0.227336	0.308531	0.219344	0.319798
1980	0.234594	0.296553	0.224022	0.318377
1981	0.238020	0.300722	0.232571	0.305427
1982	0.241332	0.272362	0.259666	0.298043
1983	0.248245	0.288129	0.258111	0.283829
1984	0.257184	0.311170	0.254270	0.266186
1985	0.260342	0.296892	0.268911	0.260342
1986	0.261721	0.293838	0.275485	0.255673

obs	EEP	EPK	EPL	EPE
1960	0.173084	0.139780	0.408111	0.096017
1961	0.164244	0.151625	0.411441	0.088723
1962	0.168632	0.150772	0.415963	0.096076
1963	0.165463	0.151522	0.420112	0.093087
1964	0.147139	0.153033	0.424261	0.072680
1965	0.141488	0.155515	0.421378	0.067343
1966	0.160557	0.149956	0.426382	0.087734
1967	0.154176	0.147687	0.429859	0.080178
1968	0.162132	0.151684	0.430580	0.091936
1969	0.173269	0.146487	0.419832	0.103700
1970	0.172775	0.153102	0.410011	0.101310
1971	0.185477	0.140350	0.413336	0.123183
1972	0.191456	0.168189	0.382476	0.145349
1973	0.179523	0.185632	0.386896	0.124272
1974	0.175515	0.200993	0.381907	0.122622
1975	0.153796	0.231791	0.401750	0.106142
1976	0.160195	0.237545	0.387849	0.129527
1977	0.157038	0.259347	0.372383	0.139646
1978	0.166086	0.245515	0.365315	0.146033
1979	0.172925	0.235162	0.360528	0.143645
1980	0.172613	0.238190	0.357086	0.153150
1981	0.174317	0.246738	0.344355	0.155556
1982	0.166785	0.270885	0.332668	0.164953
1983	0.172862	0.270146	0.320156	0.167996
1984	0.181085	0.267514	0.304944	0.171461
1985	0.177408	0.280583	0.296892	0.177408
1986	0.176504	0.286724	0.291640	0.179328

APPENDIX D4: Estimated *"intermediate"* elasticities from the *paper industry* model

obs	OKK	OLL	OEE	OPP
1960	-1.458342	-1.223229	-0.810077	-1.821650
1961	-2.006050	-1.201971	-0.734720	-1.887087
1962	-2.021438	-1.173350	-0.769581	-1.983872
1963	-2.049384	-1.154204	-0.739538	-2.001305
1964	-2.040255	-1.148623	-0.554567	-1.871751
1965	-2.087401	-1.165422	-0.498788	-1.824317
1966	-2.001961	-1.128571	-0.689525	-1.995358
1967	-1.901835	-1.119259	-0.624605	-1.938410
1968	-2.085040	-1.103477	-0.701898	-2.090924
1969	-1.913600	-1.151114	-0.809743	-2.050761
1970	-2.090064	-1.197675	-0.804790	-1.998569
1971	-1.701517	-1.173082	-0.896948	-2.117140
1972	-2.374663	-1.294263	-0.938128	-2.319013
1973	-2.424148	-1.273197	-0.878173	-2.327859
1974	-2.382371	-1.288475	-0.858575	-2.429292
1975	-2.179642	-1.171247	-0.645126	-2.894113
1976	-2.127493	-1.218922	-0.814255	-3.144662
1977	-1.962196	-1.274328	-0.845625	-3.454072
1978	-2.070685	-1.320095	-0.893923	-3.178937
1979	-2.157109	-1.358924	-0.903623	-2.888754
1980	-2.128625	-1.367161	-0.922846	-3.034054
1981	-2.071039	-1.431622	-0.929402	-3.004815
1982	-1.885718	-1.469592	-0.935008	-3.396853
1983	-1.899380	-1.544520	-0.943947	-3.204631
1984	-1.929591	-1.640010	-0.950708	-2.960696
1985	-1.832000	-1.672000	-0.952000	-3.144000
1986	-1.789139	-1.697340	-0.952378	-3.193742

obs	OKL	OKE	OKP	OLE
1960	0.365309	1.084520	1.247581	1.018963
1961	0.432612	1.070937	1.213393	1.017803
1962	0.424482	1.072101	1.205645	1.017840
1963	0.422343	1.070155	1.202638	1.017294
1964	0.418445	1.064499	1.212187	1.015793
1965	0.434063	1.062165	1.212237	1.015642
1966	0.403410	1.069314	1.206126	1.016544
1967	0.382179	1.069172	1.216144	1.015943
1968	0.409650	1.067879	1.194525	1.016373
1969	0.397114	1.076503	1.207717	1.018070
1970	0.446608	1.072171	1.200006	1.018571
1971	0.374500	1.087523	1.214148	1.019925
1972	0.556818	1.072278	1.154709	1.023224
1973	0.603912	1.057933	1.135996	1.020828
1974	0.647176	1.051100	1.118856	1.020624
1975	0.685682	1.036774	1.086586	1.016660
1976	0.706756	1.039061	1.078503	1.018968
1977	0.746562	1.035933	1.065664	1.020190
1978	0.736282	1.040532	1.074908	1.021886
1979	0.727111	1.043593	1.085278	1.022748
1980	0.734070	1.044033	1.080647	1.023579
1981	0.755178	1.042874	1.078073	1.024938
1982	0.787885	1.038596	1.063416	1.025911
1983	0.796835	1.039931	1.066768	1.027988
1984	0.806591	1.041993	1.072069	1.030918
1985	0.822000	1.040000	1.065000	1.032000
1986	0.829777	1.039157	1.062629	1.032757

obs	OLP	OEP
1960	1.157029	0.612434
1961	1.151399	0.601991
1962	1.143841	0.622633
1963	1.141213	0.617838
1964	1.146876	0.564738
1965	1.150965	0.548285
1966	1.139085	0.606543
1967	1.140833	0.586573
1968	1.132645	0.620839
1969	1.138695	0.640765
1970	1.145490	0.633337
1971	1.137820	0.676273
1972	1.140526	0.716798
1973	1.138216	0.689411
1974	1.135609	0.692260
1975	1.110893	0.688471
1976	1.107766	0.734094
1977	1.104299	0.758222
1978	1.114344	0.755476
1979	1.125799	0.741175
1980	1.122081	0.757678
1981	1.128374	0.759070
1982	1.120352	0.782611
1983	1.132295	0.778773
1984	1.150001	0.772932
1985	1.147000	0.785000
1986	1.148108	0.788386

obs	EKK	ELL	EEE	EPP
1960	-0.139054	-0.415885	-0.163210	-0.661596
1961	-0.217012	-0.414472	-0.140953	-0.670194
1962	-0.219732	-0.412383	-0.150788	-0.682265
1963	-0.224796	-0.410864	-0.142273	-0.684362
1964	-0.223124	-0.410402	-0.097793	-0.668212
1965	-0.231966	-0.411766	-0.086143	-0.661954
1966	-0.216296	-0.408675	-0.129093	-0.683649
1967	-0.199657	-0.407836	-0.113393	-0.676687
1968	-0.231511	-0.406359	-0.132253	-0.694794
1969	-0.201533	-0.410609	-0.163102	-0.690189
1970	-0.232482	-0.414173	-0.161515	-0.684034
1971	-0.170208	-0.412362	-0.196323	-0.697741
1972	-0.309327	-0.419759	-0.220812	-0.718988
1973	-0.358296	-0.418745	-0.187986	-0.719865
1974	-0.391308	-0.419492	-0.180157	-0.729622
1975	-0.434427	-0.412221	-0.118210	-0.768395
1976	-0.440319	-0.415609	-0.164568	-0.786044
1977	-0.452917	-0.418803	-0.175343	-0.805418
1978	-0.445569	-0.420848	-0.194910	-0.788313
1979	-0.437114	-0.422166	-0.199558	-0.767996
1980	-0.440203	-0.422397	-0.210090	-0.778492
1981	-0.445539	-0.423600	-0.214308	-0.776434
1982	-0.456348	-0.423805	-0.218334	-0.802014
1983	-0.455831	-0.423072	-0.226148	-0.789993
1984	-0.454541	-0.419769	-0.235110	-0.773278
1985	-0.458000	-0.418000	-0.238000	-0.786000
1986	-0.458899	-0.416333	-0.239131	-0.789283

obs	EKL	EKE	EKP	ELK
1960	0.124201	0.218504	0.453103	0.088291
1961	0.149176	0.205455	0.430934	0.099219
1962	0.149187	0.210063	0.414628	0.099825
1963	0.150342	0.205878	0.411251	0.100766
1964	0.149510	0.187715	0.432749	0.100524
1965	0.153363	0.183440	0.439860	0.101900
1966	0.146082	0.200197	0.413242	0.099532
1967	0.139259	0.194102	0.424549	0.096996
1968	0.150855	0.201212	0.396929	0.102196
1969	0.141653	0.216834	0.406460	0.097107
1970	0.154443	0.215176	0.410716	0.101787
1971	0.131644	0.238036	0.400144	0.092518
1972	0.180589	0.252388	0.358007	0.116449
1973	0.198622	0.226467	0.351294	0.130267
1974	0.210703	0.220555	0.336041	0.142375
1975	0.241326	0.189974	0.288492	0.169513
1976	0.240978	0.210003	0.269584	0.173800
1977	0.245355	0.214804	0.248491	0.188023
1978	0.234728	0.226877	0.266556	0.176837
1979	0.225886	0.230469	0.288529	0.167744
1980	0.226798	0.237679	0.277277	0.170258
1981	0.223449	0.240473	0.278570	0.173836
1982	0.227213	0.242523	0.251078	0.188389
1983	0.218267	0.249143	0.262975	0.184480
1984	0.206451	0.257685	0.280004	0.178329
1985	0.205500	0.260000	0.266250	0.184000
1986	0.203532	0.260920	0.262612	0.185684

obs	ELE	ELP	EEK	EEL
1960	0.205296	0.420215	0.095621	0.357202
1961	0.195262	0.408917	0.108545	0.363421
1962	0.199431	0.393373	0.109063	0.370371
1963	0.195708	0.390247	0.110065	0.375732
1964	0.179126	0.409433	0.109768	0.379018
1965	0.175405	0.417628	0.111556	0.375004
1966	0.190318	0.390273	0.108416	0.383129
1967	0.184439	0.398258	0.105346	0.386321
1968	0.191508	0.376367	0.111427	0.389844
1969	0.205065	0.383231	0.105647	0.375657
1970	0.204419	0.392058	0.111602	0.363690
1971	0.223240	0.374989	0.100307	0.368457
1972	0.240842	0.353609	0.130694	0.337730
1973	0.218524	0.351981	0.148415	0.344052
1974	0.214160	0.341073	0.165023	0.340727
1975	0.186288	0.294945	0.200612	0.372231
1976	0.205942	0.276899	0.208238	0.358221
1977	0.211540	0.257500	0.232363	0.344273
1978	0.222811	0.276335	0.216453	0.332785
1979	0.225865	0.299302	0.203754	0.323773
1980	0.233023	0.287909	0.207929	0.321538
1981	0.236337	0.291568	0.216333	0.307279
1982	0.239560	0.264521	0.243507	0.299067
1983	0.246282	0.279129	0.241431	0.283313
1984	0.254946	0.300359	0.236910	0.263903
1985	0.258000	0.286750	0.251500	0.257500
1986	0.259313	0.283737	0.258063	0.252474

obs	EEP	EPK	EPL	EPE
1960	0.222427	0.096853	0.369589	0.185380
1961	0.213795	0.110156	0.375964	0.176923
1962	0.214127	0.110763	0.384861	0.179861
1963	0.211274	0.111801	0.390434	0.176796
1964	0.201610	0.111371	0.390556	0.163798
1965	0.198945	0.113169	0.385314	0.160867
1966	0.207813	0.110087	0.397711	0.172488
1967	0.204769	0.106876	0.399751	0.167949
1968	0.206299	0.113260	0.406207	0.173037
1969	0.215651	0.107294	0.391866	0.184065
1970	0.216767	0.113401	0.378308	0.183746
1971	0.222878	0.101855	0.386390	0.197946
1972	0.222236	0.133545	0.355874	0.209644
1973	0.213193	0.152041	0.361424	0.192727
1974	0.207916	0.169641	0.358394	0.188722
1975	0.182791	0.208289	0.395339	0.165025
1976	0.183495	0.217248	0.384218	0.178576
1977	0.176802	0.244531	0.371724	0.180802
1978	0.187343	0.226382	0.356918	0.190432
1979	0.197047	0.211906	0.344423	0.194425
1980	0.194409	0.216802	0.343557	0.198569
1981	0.196141	0.225875	0.327399	0.200956
1982	0.184778	0.256885	0.321141	0.200254
1983	0.191980	0.254007	0.302224	0.206049
1984	0.201875	0.248311	0.279283	0.213581
1985	0.196250	0.265000	0.273250	0.214000
1986	0.194837	0.272464	0.267927	0.214353

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ISBN 951-40-1093-0
ISSN 0001-5636