A DYNAMIC FACTOR DEMAND MODEL FOR THE SWEDISH PULP INDUSTRY — AN EULER EQUATION APPROACH

TOMMY LUNDGREN AND MAGNUS SJÖSTRÖM[*]

ABSTRACT

In this paper, we specify and estimate a dynamic factor demand model for the Swedish pulp industry. Firms are assumed to have rational expectations, and costs of adjustment are assumed to arise when the capital stock is altered. The model is estimated using firm specific translog cost functions, and panel data from 1972 to 1990. We find weak evidence of adjustment costs for capital. The average marginal adjustment cost is about 10 percent of the price of capital. All of the estimated own–price elasticities are negative, and the empirical cost functions have the desired properties from theory. Short- and long-term elasticities are calculated and the variances are estimated using the bootstrap technique. The results suggest that the user cost of capital is a significant determinant of pulp industry investments, while output level is not. We also find that pulp industry investments are insensitive to variations in the price of electricity.

Keywords: bootstrap, dynamic factor demand, panel data.

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INTRODUCTION

The forest sector is one of the major industries in Sweden, and its well-being is crucial for the balance of the whole economy. Thus, it is important to acquire an understanding of how a forest industry firm will respond to changes in its economic environment. The forest industry is Sweden's largest consumer of electricity. In 1980 Sweden decided to phase out nuclear power in favor of alternative

[*] Tommy Lundgren, Department of Forest Economics, Swedish University of Agricultural Sciences, SE-901 83 Umeå, Sweden.

Magnus Sjöström, Department of Economics, University of Umeå, SE-901 87 Umeå, Sweden.

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energy sources. The phase-out process has been delayed, but according to the present government, the shut-down of two nuclear power plants in the south of Sweden is imminent. It is uncertain about how this will affect energy-intensive industries, such as the forest sector. The Swedish forest sector is capital intensive. The capital stock is, on average, 1.5 million SEK per employee in the pulp paper industry, which is more than 2.5 times the average capital-labor ratio in the Swedish manufacturing industry as a whole. Forest industry investments are 20–25% of total investments in manufacturing. It is important to understand the driving forces behind investment decisions. This paper is an attempt to provide such understanding and a complete description of pulp industry technology.

We use a dynamic model of the production structure with an adjustment process for a quasi-fixed input factor. This enables us to analyze both short- and long-term elasticities for capital and other inputs. Studies of factor demand have been performed in both static and dynamic frameworks. The dynamic model framework can be divided into three subgroups: first-, second-and third-generation dynamic models of factor demands.[1] First-generation dynamic models are single-equation models using the Koyck-type of partial adjustment processes, or similar adjustment processes, for all input factors. These models are often criticized for the lack of theoretical underpinnings. In addition, interdependence between inputs are neglected. Second-generation dynamic models incorporate interrelated factor demands into a firm's short-term demand responses, but the role of economic theory is still limited since economic factors affecting the time path of adjustment from the short-term to the long-term are not formally introduced. The distinguishing feature of the third-generation dynamic models is that they are based explicitly upon dynamic optimization, incorporating adjustment costs for quasi-fixed factors of production, and therefore provide well-defined measures of short- and long-term elasticities. The theoretical foundations of third-generation dynamic models are mainly drawn from Lucas

[1] See the survey in Hartman (1979).

(1967a, b), Lau (1976) & McFadden (1978). A nice overview of this theory can be found in Chapter 12 in Berndt & Field (1981).

The model we develop in this paper is based on the models in Pindyck & Rotemberg (1983a) and Pindyck & Rotemberg (1983b). Firms operate in a stochastic environment, have rational expectations, maximize the expected future discounted flow of profits, and minimize the expected discounted flow of costs. By specifying a restricted cost function, we can derive a stochastic Euler equation for the quasi-fixed inputs. We estimate a translog restricted cost function together with an Euler equation for a quasi-fixed input and the cost share equations for the flexible inputs, using a two-stage instrumental variable estimation technique applied to a panel data set. The Euler equation does not provide us with a complete solution to the dynamic optimization problem, but we are able to estimate it directly given any parametric specification of the technology. This will enable us to test whether the empirical cost function has the properties of the theoretical cost function, constant returns to scale, and the existence of adjustment costs for quasi-fixed inputs. The estimation results gives us a parameterization of the production technology in the pulp industry, which can be used to calculate short- and long-term demand elasticities.

The remainder of this paper is organized as follows. After a breif presentation of the theory underlying our approach, we develop the empirical model by specifying the restricted cost function and the adjustment cost function. The next two sections describes the data, the estimation procedure, and the specification tests applied to the empirical model. Parameter estimates, elasticities, and concluding remarks are presented in the last two sections of the paper.

THEORY

Define a production function of a single-output representative firm as

$$Y = F(\mathbf{v},\mathbf{x},\mathbf{z},t), \tag{1}$$

where Y is output, $\mathbf{v}$ is a vector of variable inputs, $\mathbf{x}$ is a vector of quasi-fixed inputs, $\mathbf{z}$ is a vector of gross changes in the quasi-fixed inputs, and t represents state technology.

A change in the levels of the quasi-fixed factors will result in internal costs of adjustment because of the necessity of devoting resources to change the input stock rather than to produce output. The costs of adjustment are represented by the convex vector function

$$C(\mathbf{z},\mathbf{x}) = \begin{bmatrix} C(z_{1,t}, x_{1,t}) \\ C(z_{2,t}, x_{2,t}) \\ \vdots \\ C(z_{l,t}, x_{l,t}) \end{bmatrix}, \tag{2}$$

where l is the number of quasi-fixed inputs. The evolution over time for the quasi-fixed inputs is represented by the function

$$z_{j,t} = x_{j,t} - (1-\delta_j)x_{j,t-1}; \quad j = 1,\ldots,l, \tag{3}$$

where z_j and x_j are the gross addition and level of the jth stock, respectively, and $0 \leq \delta_j < 1$ is the rate of depreciation for the *jth* quasi-fixed input.

In the short run, firms maximize restricted variable profits (revenue minus variable costs) conditional on a variable input price vector $\mathbf{p}$, output price P, the vector of quasi-fixed inputs $\mathbf{x}$ and output level Y. Alternatively, firms minimize variable costs, $\sum_{i=1}^{k} p_{i,t} v_{i,t}$, conditional on $\mathbf{p}$, $\mathbf{x}$, t, and Y. The restricted cost function, G_t, is then formulated as

$$G_t = G(\mathbf{p},\mathbf{x},Y,t). \tag{4}$$

This function can be shown, under reasonable regularity conditions on F, to be increasing and concave in $\mathbf{p}$ and decreasing and convex in $\mathbf{x}$. The cost-minimizing demand equations for the variable inputs, $v_{i,t}$, are given by the Shepard-Uzawa-McFadden lemma

$$\frac{\partial G_t}{\partial p_{i,t}} = v_{i,t}, \tag{5}$$

for $i = 1,\ldots,k$.

The long-term dynamic problem facing a firm is to minimize the expected present value of the future stream of costs with respect to the level and gross addition of the quasi-fixed inputs,

$$\mathcal{E}_0[PV] = \min_{\{\mathbf{x},\mathbf{z}\}} \mathcal{E}_t \left\{ \sum_{t=0}^{\infty} R_t \left[G(\mathbf{p},\mathbf{x},Y) + \sum_{j=1}^{l} a_{j,t} x_{j,t} \right.\right.$$
$$\left.\left. + \sum_{j=1}^{l} C\left(z_{j,t}, x_{j,t}\right) \right] \right\}, \quad (6)$$

subject to a set of equations of motion, (3), and any constraints on stock or flow variables in the model. The time t expectations operator is denoted $\mathcal{E}_t$, R_t is a discount factor and a_j is the user cost, or rental cost, of the jth quasi–fixed factor.[2]

The optimization problem facing a firm is to find combinations among all the possible $G(\mathbf{p},\mathbf{x},Y)$, so that time paths of the state vector $\mathbf{x}$ and the control vector $\mathbf{z}$, minimize the expected present value of total costs. A solution can be obtained using methods of dynamic optimization.[3] However, in the empirical model, we only use the marginal condition, or the Euler equation, for capital, so there is no need to explicitly find the optimal time paths for the control and state variables within the framework of this paper.

MODEL

Firms in the pulp industry choose the optimal levels of capital (K), labor (L), electricity (E) and pulpwood (M). The input prices are denoted q, w, e, and m respectively. Labor, electricity, and pulpwood are treated as flexible factors, while capital is quasi-fixed. The technology for each firm is described by the twice-differentiable production function

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[2] For example, in the case of capital, user cost is usually defined as $\frac{q}{p}(r+\delta)$ where q is the acquisition price for new capital, p is the output price, r is the real financial cost of capital, and δ is the depreciation rate. See Jorgenson (1963).

[3] Bellman's dynamic programming or Pontryagin's maximum principle.

$$Y_{i,t} = F\left(K_{i,t}, L_{i,t}, E_{i,t}, M_{i,t}, t\right), \tag{7}$$

where *i* is a firm subscript and *t* denotes time subscript and state technology. Assuming a cost-minimizing behavior, we write the restricted cost function as

$$G_{i,t} = G\left(w_{i,t}, e_{i,t}, m_{i,t}, K_{i,t}, Y_{i,t}\right). \tag{8}$$

Variable cost depends upon flexible input prices and levels of the quasi–fixed variable. Changes in $K_{i,t}$ will result in costs of adjustment given by the convex function $C_{i,t} = C(I_{i,t},K_{i,t})$, where I is the gross investment defined at time t as

$$I_{i,t} = K_{i,t} - \left(1 - \delta_K\right) K_{i,t-1}. \tag{9}$$

Capital is assumed to deteriorate at a constant rate given by δ_K.

All variables in the current period are known, whereas future variables are stochastic. A firm's management is risk neutral, has rational expectations, and acts on behalf on the shareholders in order to maximize the value of the firm by minimizing costs.

The cost-minimizing variable factor demand equations are are given by:

$$L_{i,t} = \frac{\partial G_{i,t}}{\partial w_{i,t}},$$
$$E_{i,t} = \frac{\partial G_{i,t}}{\partial e_{i,t}},$$
$$M_{i,t} = \frac{\partial G_{i,t}}{\partial m_{i,t}}. \tag{10}$$

The stochastic dynamic optimization problem facing a firm is to solve

$$\min_{\{K_{i,t}, I_{i,t}\}} \quad \varepsilon_{i,t}\left\{\sum_{t=0}^{\infty} R_t \Big[G\left(w_{i,t}, e_{i,t}, m_{i,t}, K_{i,t}, Y_{i,t}\right) + q_{i,t} K_{i,t} + C\left(I_{i,t}, K_{i,t}\right)\Big]\right\}, \tag{11}$$

subject to the equation of motion for capital, (9). The expectation operator, $\varepsilon_{i,t}$, is conditional on information available to firm management in period t. Time enters the function explicitly in the form of a discount factor $R_t = (1 + r_t)^{-t}$, where r_t is the real discount rate.

This optimization problem can be represented with the following value function:[4]

$$V(K_{i,t}, t) = g(K_{i,t}, I_{i,t}) + \varepsilon_{i,t}\left\{R_t\left[V(K_{i,t+1}, t+1)\right]\right\}, \tag{12}$$

where

$$g(K_{i,t}, I_{i,t}) = G(w_{i,t}, e_{i,t}, m_{i,t}, K_{i,t}, Y_{i,t}) + q_{i,t}K_{i,t} + C(I_{i,t}, K_{i,t}). \tag{13}$$

By differentiating the value function with respect to $K_{i,t}$, we obtain the stochastic Euler equation

$$\frac{\partial G_{i,t}}{\partial K_{i,t}} + q_{i,t} + \frac{\partial C_{i,t}}{\partial K_{i,t}} + \varepsilon_{i,t}\left[R_t\left(\frac{\partial V(K_{i,t+1}, t+1)}{\partial K_{i,t}}\right)\right] = 0, \tag{14}$$

or

$$\frac{\partial G_{i,t}}{\partial K_{i,t}} + q_{i,t} + \frac{\partial C_{i,t}}{\partial K_{i,t}} + R_t\left(\frac{\partial C_{i,t+1}}{\partial K_{i,t}}\right) = \xi_{i,t+1}, \tag{15}$$

where $\xi_{i,t+1}$ is a forecast error which, under the assumption of rational expectations, is $iid(0,\sigma^2)$. That is, the forecast error has a zero mean and finite variance. Thus, at the optimum, the marginal benefit from increasing the capital stock in time t should be equal to the rental price of capital plus the marginal adjustment cost at time t and the expected discounted savings in the future adjustment costs by installing capital now instead of in the future. The transversality condition is written as

[4] This type of value function is known as the stochastic Bellman equation. See, for example, Dixit (1990) ch 10 and 11 for an intuitive discussion of this concept.

$$\lim_{n\to\infty} \quad \varepsilon_{i,t}\left[R_t\left(\frac{\partial G_{i,t}}{\partial K_{i,t}}+q_{i,t}+\frac{\partial C_{i,t}}{\partial K_{i,t}}\right)\right]=0, \tag{16}$$

for $t = 0, \ldots, n$.

When management looks far into the future, the optimal level of capital should not differ from the level of capital the firm would hold in the absence of adjustment costs.

Firms must also choose $Y_{i,t}$ in order to solve their intertemporal profit-maximization problem.[5] This would require an additional first-order condition in our model. The choice of optimal $Y_{i,t}$ depends on such things as output market structure and costs of price adjustments. Given assumptions about a firm's market environment, it would be possible to formulate this first-order condition and include it in the model in order to improve the efficiency of the empirical parameter estimates. However, if these assumptions are incorrect, the empirical model would generate inconsistent parameter estimates.

To estimate the model, we need to specify the functional forms of $G_{i,t}$ and $C_{i,t}$. A convenient functional form for adjustment costs, introduced by Summers (1981), is[6]

$$C_{i,t}=C\left(I_{i,t},K_{i,t}\right)=\frac{\beta}{2}\left(\frac{I_{i,t}}{K_{i,t}}-\omega\right)^2 K_{i,t}. \tag{17}$$

This has the property that adjustment costs are strictly convex in I and homogenous of degree one in its arguments. Total costs of adjustment are quadratic about some ''normal'' rate of gross investment ω. This is the rate of investment at which adjustment costs average zero. Marginal adjustment costs with respect to gross investment,

$$\frac{\partial C_{i,t}}{\partial I_{i,t}}=\beta\frac{I_{i,t}}{K_{i,t}}-\beta\omega, \tag{18}$$

[5] Note that as long as revenues depend solely on the level of output and not on the choice of inputs, the maximization of profits would imply minimization of costs.

[6] The quadratic form reduces the number of parameters to estimate. For further comments see, for example, Kennan (1979) and Meese (1980). This functional form is also used by Blundell *et al.* (1992).

are linear at the observed rate of investment and ''normal'' rate of investment. The adjustment cost parameter is assumed to be non-negative, $\beta \geq 0$.[7] Marginal adjustment cost with respect to the level of the capital stock, $\partial C_{i,t}/\partial K_{i,t}$, is negative and usually referred to as the installation experience effect. Define $K_{i,t}^{1} > K_{i,t}^{2}$. For a given amount of gross investment $I_{i,t}$, the larger capital stock, $K_{i,t}^{1}$, will generate less adjustment costs than the er capital stock, $K_{i,t}^{2}$.

When specifying the restricted cost function, we use the translog form developed by Kmenta (1967) and introduced formally in a series of papers in the early seventies, including Berndt & Christensen (1972) and Christensen *et al.* (1973). By imposing parameter restrictions, the function is made symmetric and homogeneous of degree one in prices. We write the cost function for firm *i* in period *t* as:

$$
\begin{aligned}
\log G_{i,t} = {} & f_i + \alpha_0 + \log m_{i,t} + \alpha_1 \log\left(\frac{e_{i,t}}{m_{i,t}}\right) + \alpha_2 \log\left(\frac{w_{i,t}}{m_{i,t}}\right) \\
& + \alpha_3 \log K_{i,t} + \alpha_4 \log Y_{i,t} + \frac{1}{2}\gamma_{11}\left[\log\left(\frac{e_{i,t}}{m_{i,t}}\right)\right]^2 \\
& + \gamma_{12} \log\left(\frac{e_{i,t}}{m_{i,t}}\right) \log\left(\frac{w_{i,t}}{m_{i,t}}\right) + \gamma_{13}\left(\frac{e_{i,t}}{m_{i,t}}\right) \log K_{i,t} \\
& + \gamma_{14} \log\left(\frac{e_{i,t}}{m_{i,t}}\right) \log Y_{i,t} + \frac{1}{2}\gamma_{22}\left[\log\left(\frac{w_{i,t}}{m_{i,t}}\right)\right]^2 \\
& + \gamma_{23} \log\left(\frac{w_{i,t}}{m_{i,t}}\right) \log K_{i,t} + \gamma_{24} \log\left(\frac{w_{i,t}}{m_{i,t}}\right) \log Y_{i,t} \\
& + \frac{1}{2}\gamma_{33}\left(\log K_{i,t}\right)^2 + \gamma_{34} \log K_{i,t} \log Y_{i,t} \\
& + \frac{1}{2}\gamma_{44}\left(\log Y_{i,t}\right)^2 + \lambda t. \qquad (19)
\end{aligned}
$$

[7] The parameter β is the equivalent to the parameter in *q*-models of investment.

The firm-specific effects are represented by f_i and λ is the rate of technical progress. The cost-share equations derived from the translog cost function are as follows:

$$S_{L,i,t} = \frac{\partial \log G_{i,t}}{\partial \log w_{i,t}} = \alpha_2 + \gamma_{12} \log\left(\frac{e_{i,t}}{m_{i,t}}\right) + \gamma_{22} \log\left(\frac{w_{i,t}}{m_{i,t}}\right) + \gamma_{23} \log K_{i,t} + \gamma_{24} \log Y_{i,t}, \quad (20)$$

$$S_{E,i,t} = \frac{\partial \log G_{i,t}}{\partial \log e_{i,t}} = \alpha_1 + \gamma_{11} \log\left(\frac{e_{i,t}}{m_{i,t}}\right) + \gamma_{12} \log\left(\frac{w_{i,t}}{m_{i,t}}\right) + \gamma_{13} \log K_{i,t} + \gamma_{14} \log Y_{i,t}, \quad (21)$$

and by symmetry,

$$S_{M,i,t} \equiv 1 - S_{E,i,t} - S_{L,i,t}. \quad (22)$$

With the adjustment cost function and the restricted cost function specified as above, the empirical stochastic Euler equation for capital becomes

$$\frac{G_{i,t} S_{K,i,t}}{K_{i,t}} + q_{i,t} + \beta\left[\left(\frac{I_{i,t}}{K_{i,t}} - \omega\right)\left(1 - \frac{I_{i,t}}{K_{i,t}}\right) + \frac{1}{2}\left(\frac{I_{i,t}}{K_{i,t}} - \omega\right)^2\right] - \varepsilon_{i,t}\left\{R_t\left[\beta(1-\delta_K)\left(\frac{I_{i,t+1}}{K_{i,t+1}} - \omega\right)\right]\right\} = 0, \quad (23)$$

which also can be written as

$$\frac{G_{i,t} S_{K,i,t}}{K_{i,t}} + q_{i,t} + f\left[\frac{\partial C_{i,t}}{\partial K_{i,t}}, R_t\left(\frac{\partial C_{i,t+1}}{\partial K_{i,t}}\right)\right] = \xi_{i,t+1}. \quad (24)$$

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[8] Note that in this case, it is neutral disembodied technical progress.

where the right-hand side is the t + 1 forecast error described earlier and

$$S_{K,i,t} = \frac{\partial \log G_{i,t}}{\partial \log K_{i,t}} = \alpha_3 + \gamma_{13} \log\left(\frac{e_{i,t}}{m_{i,t}}\right)$$
$$+ \gamma_{23} \log\left(\frac{w_{i,t}}{m_{i,t}}\right) + \gamma_{33} \log K_{i,t} + \gamma_{43} \log Y_{i,t}. \qquad (25)$$

The cost function and the cost-share equations can be transformed into regression equations by adding the appropriate error term to each one.

In the adjustment cost literature, the ''normal'' rate of investment parameter ω enters the empirical model in different ways. Chirinko (1987) treats ω as a given constant and sets it equal to the depreciation rate δ. Hubbard *et al.* (1985) use a fixed value of 0.1. Whited (1992) estimated ω to be approximately equal to one, which, in most cases, must be considered unrealistic. We have chosen to follow Chirinko (1987) since the ''normal'' rate of investment should be close to the depreciation rate, δ_K, when the capital stock is at steady state.

The model can be used to derive formulas for 15 short- and 20 long-term factor demand elasticities. Short-term elasticities are calculated given that only flexible inputs change, while the long-term elasticities apply when the quasi-fixed input also adjusts. It should be noted that the long-term elasticities must be interpreted with some caution. We have implicitly assumed that firms do not consider the variance of future price paths (over the long term) when responding to immediate price changes. If prices evolve stochastically, the adjustment paths for any discrete change in a price to a new long-term expected equilibrium are solutions to a stochastic control problem. However, such solutions are rarely feasible, and we have to use the solution to a deterministic control problem in order to compute and estimate the long-term elasticities. (Elasticity formulas are available from the authors)

DATA

To estimate the model, we use a unique plant-level panel data set which contains cross-section data from 22 Swedish pulp mills with annual observations from 1972 to 1990.

The use of data on individual firms has several advantages over the use of aggregate time-series analysis: biases resulting from aggregation across firms are eliminated; cross-sectional variation contributes to enhanced precision of model parameters estimates; many variables can be measured more accurately at the level of the individual firm; and heterogeneity across firms can be explicitly modeled. Using data at the micro-level allows us to move away from the notion of the representative firm so that cross-firm differences can be investigated more thoroughly.

The factor prices *e*, *w*, and *m* are firm specific. That is, these prices are calculated using firm-level information on how much of each input is used and how much it costs. However, note that *w* does not vary much over firms. The user, or rental, cost of capital *q* is not firm specific. The calculation of this variable is based on the real financial cost of capital rates for the whole manufacturing industry.[9]All stock variables, which are measured in SEK, and all nominal prices, are deflated using the appropriate price indices (1981 as base year). The capital stocks are calculated using the perpetual inventory method with a constant depreciation rate. The parameters δ_K and ω are set to 0.0812.[10] Initially, we had 418 observations (22 firms and 19 annual observations), but after removing a few obvious outliers and selecting only non-zero values of factor inputs, factor prices, and gross investment, we were left with 278 observations.

[9] The user cost of capital was calculated using the following formula:

$$q = \left(\frac{w_m p_m + w_b p_b}{p} \right) \left(w_m \left(r_m + \delta_m \right) + w_b \left(r_b + \delta_b \right) \right),$$

where p_m and p_b are investment good price indices for machinery and buildings, respectively; p is a producer price index for the pulp industry; w_m and w_b are weights corresponding to mean values of the investment ratio for machinery and buildings (0.9 and 0.1); r_m, r_b, δ_m and δ_b are real financial cost of capital rates and depreciation rates for machinery and buildings. Real financial cost of capital rates were calculated and supplied by Jan Södersten, Department of Economics, Uppsala University.

[10] The depreciation rate is calculated as $\delta = \mathrm{w}_m \delta_m + \mathrm{w}_b \delta_b$. The depreciation rates for machinery and buildings are 0.087 and 0.029 respectively ($\mathrm{w}_m = 0.9$ and $\mathrm{w}_b = 0.1$). The depreciation rates were derived for the Swedish forest industry for the period 1980–90 by Statistics Sweden (SCB).

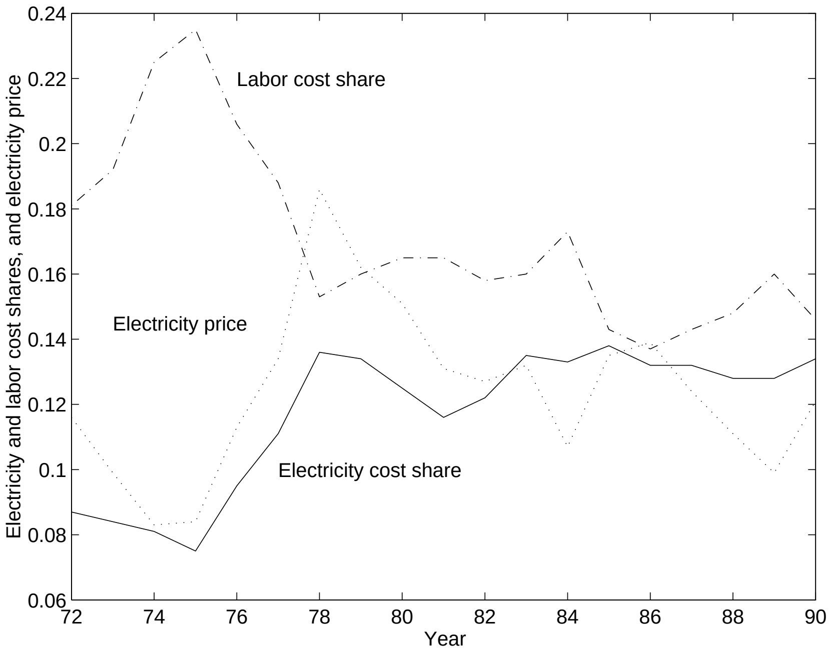

FIGURE 1. COST SHARES AND ELECTRICITYPRICE (BASE YEAR = 1981).

As can be seen in Figure 1 the labor and the electricity cost shares seem to be negatively correlated. Without further investigation it is tempting to draw the conclusion that labor and electricity are substitutes. However, as the results will show, they are in fact mild complements. The rise in the electricity cost share during the late seventies is mainly a result of the sharp increase in electricity price (also included in Figure 1), and not a consequence of labor-electricity substitution. The labor and electricity cost shares add up to about 30 percent of the total cost. The pulpwood cost share is stable at about 70 percent and is not included in the figure. On average, the price of electricity in the pulp industry is 0.122 SEK / kwh, which is about half what it was in the industry as a whole.

ESTIMATION

Firm-specific fixed effects are assumed to be present in the restricted cost function as the result of different unobservable managerial skills. We estimate the one-way fixed-effect model by adding ($N-1$) firm dummies to the cost function. There are no fixed effects in the marginal conditions.

The regression disturbances for the equations are assumed to be serially correlated and heteroscedastic. Serial correlation is assumed to be equal across all firms, while heteroscedasticity is assumed to be present within and across firms. A simultaneous estimation of Equations (19), (20), (21) and (23) is initially performed to estimate a set of parameters used to transform the variables in order to correct for serial correlation and cross-sectional heteroscedasticity in each equation. We assume that the disturbance follows an $AR(1)$ process and estimate equation-specific serial correlation coefficients. In addition, we estimate firm- and equation-specific variances of the disturbance to correct for heteroscedasticity across firms.[11]

After transformation, Equations (19), (20), (21) and (23) are estimated simultaneously, together with the restricted cost function (ref 23), using a two-step instrumental variable, or the Generalized Methods of Moments (GMM), estimator developed by Hansen (1982) and Hansen & Singleton (1982). The covariance matrix is made robust to within firm heteroscedasticity (White, 1980). The cost function, cost share, and Euler equation are assumed to hold in expectation of some conditioning set or instrumental variables. This conditioning set should be, if properly defined, a subset of the set that would apply to the capital Euler equation if the cost function and share equations fit without error. Therefore, we use a set of instrumental variables that does not include any current variables appearing in the econometric model. From statistical theory, it is known that the parameter estimates should not depend on the choice of instruments, as long as they are independent of the regression disturbances at time t. However, from practical experience, one can observe that this is not always true, so we check the robustness of the results by using two alternative sets of instruments — Inst set 1 and Inst set 2 in Table 1 — that do not include any current variables appearing in any of the model equations. The first instrument set includes the following variables: a constant, $Y_{i,t-1}$, $K_{i,t-1}$, $L_{i,t-1}$, $E_{i,t-1}$, $M_{i,t-1}$, $q_{i,t-1}$, $w_{i,t-1}$, $e_{i,t-1}$, $m_{i,t-1}$,

[11] For a comprehensive discussion see Kmenta (1971)

$R_{i,t-1}$, and the lagged dummy variables. The second instrument set includes the following variables: a constant, $Y_{i,t-1}$, lagged aggregated Swedish forest industry investments, lagged consumer price index, lagged pulp industry producer price index, $R_{i,t-1}$, lagged inflation rate, lagged salary paid to employees, lagged total cost of electricity, lagged total cost of raw materials, and lagged dummy variables.[12] In Table 1 we also report parameter estimates from a pooled data estimation(restricted model without firm dummies). In this estimation, the instrument sets are the same as above but the lagged dummy variables are removed.

The elasticities are nonlinear functions of the estimated parameters and cost shares. This makes it difficult to obtain appropriate estimates of the variances of the estimated elasticities. We follow Datt (1988) and Khalid Nainar (1989) and estimate the variances using the bootstrap technique.[13]

Along with parameter estimates, we report the Sargan–Hansen J-statistic. Under the null of valid restrictions, the J-statistic is asymptotically distributed as χ^2 with degrees of freedom equal to the number of overidentifying restrictions.[14] As the data is transformed to remove heteroscedasticity between firms, we use a simple Chow test to test for firm-specific effects (see for example Baltagi, 1995).

The inputs and parameter estimates generate an empirical function $G_{i,t}$ that must satisfy the monotonicity and curvature conditions at all sample points in the data set: (1) since $G_{i,t}$ should be monotonically increasing in $w_{i,t}$, $e_{i,t}$,

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[12] Time series for aggregated Swedish forest industry investments, price indices, and the inflation rate are taken from Statistics Sweden (SCB).

[13] In short, this is done in the following manner: After estimating the system of equations, we resample the 278 observations with replacement from the residual matrix. Adding these vectors of residuals to the right-hand side of the equations gives us a set of pseudodata of the endogeneous variables. Estimating the system of equations based on pseudodata and the right-hand side variables gives a new parameter vector and a new set of elasticities. This procedure is repeated 50 times, which gives us 50 estimates of each elasticity. The variances of the estimated elasticities are then simply calculated as the variance in each pseudosample of elasticities.

For an overview of this techniqe, see, for example, Efron & Tibshirani (1986) and (1993).

[14] The number of instruments times the number of equations minus the number of parameters.

and $m_{i,t}$ and decreasing in $K_{i,t}$, the estimated values of the cost shares must satisfy $0 \leq S_{L,i,t}$, $S_{E,i,t}$, $S_{M,i,t} \leq 1$, and the first partial derivative of $G_{i,t}$ with respect to $K_{i,t}$ should be less than zero ($S_{K,i,t} < 0$); (2) since $G_{i,t}$ should be concave in the flexible input prices, the Hessian matrix of $G_{i,t}$ with respect to $w_{i,t}$, $e_{i,t}$, and $m_{i,t}$ must be negative semidefinite; and (3) since $G_{i,t}$ should be convex in the quasi-fixed input capital, the second partial derivative of $G_{i,t}$ with respect to $K_{i,t}$ should be positive.

We test constant returns to scale by testing the restriction $(\partial \log G_{i,t}/\partial \log Y_{i,t})^{-1} - 1 = 0$, where $\partial \log \mathrm{G}_{i,t}/\partial \log Y_{i,t} = S_y$ (see Chambers, 1994). Under the null, a firm's technology exhibit constant returns to scale.

RESULTS

Parameter estimates are shown in in Table 1. The adjustment cost parameter β, is only significant in the fixed-effect model estimated with instrument set 1 (column 3). The use of a convex adjustment cost function might not be appropriate because of the characteristics of the investment decision in the pulp industry. According to the firm-level data, investment expenditures follow a discontinuous path with sharp spikes. This behavior may not comply with convexity in adjustment costs. The adjustment cost theory is based on the observation that aggregate investment data is continuous and smooth. The assumption of convexity will penalize lumpy investments while favoring small subsequent investments. Using the parameter estimate of β in column 3, the ex post calculated adjustment cost is, on average, about 2 percent of an investment. The marginal adjustment cost, $\partial C_{i,t}/\partial I_{i,t}$, constitutes, on average, about 10 percent of the capital rental price q_t. The distribution of the percentage adjustment cost is very skewed. This is, again, a combined result of the structure of the data and the use of a convex adjustment cost function. The structure of the minimization problem limits us to use only convex adjustment cost functions.

The J-statistic would suggest a rejection of the overidentifying restrictions at the 5 percent level in all estimated models. Possible explanations for this would be misspecification of the cost function or irrational expectations for the behavior of the firms. The model we use to

TABLE 1. GMM PARAMETER ESTIMATES.

	POOLED MODEL		FIXED EFFECTS MODEL	
Parameter	Inst set 1[a]	Inst set 2[a]	Inst set 1	Inst set 2
α_0	1.329 (3.14)	0.373 (2.09)	−4.535 (−0.39)	−13.318 (−3.62)
α_1	−0.070 (−7.97)	−0.013 (−2.00)	−0.005 (−2.02)	−0.002 (−1.35)
α_2	0.001 (0.08)	0.063 (3.57)	0.018 (3.45)	0.014 (5.51)
α_3	−0.085 (−1.16)	−0.057 (−0.71)	−0.018 (−1.05)	−0.031 (−4.42)
α_4	0.648 (4.30)	0.783 (8.29)	1.831 (1.70)	2.966 (4.81)
γ_{11}	0.015 (3.75)	0.022 (2.67)	0.020 (8.62)	0.015 (3.47)
γ_{12}	−0.044 (−7.09)	−0.115 (−6.98)	−0.042 (−8.90)	−0.032 (−6.10)
γ_{13}	0.001 (0.07)	0.005 (0.21)	−0.005 (−0.80)	0.007 (0.67)
γ_{14}	0.065 (3.84)	0.042 (2.11)	0.033 (4.35)	0.015 (1.47)
γ_{22}	−0.008 (−0.58)	−0.156 (−3.76)	0.033 (3.75)	0.032 (3.12)
γ_{23}	−0.019 (−0.94)	−0.114 (−2.63)	0.010 (0.96)	−0.001 (−0.07)
γ_{24}	0.020 (1.00)	0.099 (2.23)	−0.023 (−2.02)	−0.008 (−0.69)
γ_{33}	0.050 (0.83)	0.238 (1.76)	−0.018 (−0.54)	0.032 (1.10)
γ_{34}	−0.065 (−1.06)	−0.256 (−1.89)	−0.009 (0.24)	−0.054 (−1.69)
γ_{44}	0.145 (2.36)	0.312 (2.27)	−0.010 (−0.16)	−0.051 (−0.87)
λ	0.011 (0.78)	0.017 (3.02)	0.029 (3.19)	0.023 (2.36)
β	0.123 (1.20)	−0.273 (−1.31)	0.219 (2.11)	0.023 (0.43)
J-statistic	97.97*	39.14*	142.67*	150.35*
CRTS-test[b] (1989)	18.11*	0.295	0.017	4.832*

t -ratios within parentheses. [a] Dummy variables are removed. [b] Under null ⇒ constant returns to scale. * Exceeds critical value.

TABLE 2. COST FUNCTION PROPERTIES.

	POOLED MODEL		FIXED EFFECTS MODEL	
	Inst set 1[a]	Inst set 2[a]	Inst set 1	Inst set 2
Hessian matrix test[*]	No	No	Yes	Yes
$G_{KK} \geq 0$	Yes	No	Yes	Yes
S_E, S_L,$S_M \geq 0$ and $S_K \leq 0$	No	No	Yes	Yes

[*] Negative semidefiniteness required. [a] Dummy variables removed (see Table 1).

calculate short- and long term elasticities generates a production function that exhibits constant returns to scale (fixed effects model, inst set 1). We cannot reject the presence of fixed effects in the cost function (columns 3 and 4).

Property tests of the empirical cost function are presented in Table 2. Note that only the firm-effects models have the desired cost function properties.

Two sets of elasticities are calculated using the parameter estimates from the fixed-effects model (column 3, Table 1). Short- and long-term elasticities are presented in Table 3. We have chosen to evaluate the elasticities at the means over firms for 1989. All short- and long-term own-price elasticities have the expected sign, and in the case of electricity and labor, they are also about the same size, implying fast adjustment to long-term steady-state levels.[15] The own-price elasticity of pulpwood is substantially lower than the others, indicating a relative inelastic demand for raw materials. Our interpretation of this result is that the pulp industry plants have limited opportunities to substitute pulpwood for other inputs. None of the elasticities, that are significantly different from zero, change signs between short- and long-term. The elasticity estimates imply that, except for labor demand with re-

[15] In an alternative model specification, including convex labor adjustment costs, we found no evidence supporting the presence of costs associated with changing the stock of labor (hours worked).

TABLE 3. DEMAND ELASTICITIES (1989).

	Short-term		
	E	*M*	*L*
e	–0.708	0.207	–0.160
	(–16.43)	(4.23)	(–2.25)
m	0.821	–0.257	0.774
	(9.79)	(–5.62)	(7.09)
w	–0.114	0.138	–0.614
	(–1.62)	(4.34)	(–4.97)
K	–0.361	–0.336	–0.249
	(–4.02)	(–5.64)	(–1.49)
Y	1.584	1.378	1.214
	(1.64)	(1.37)	(1.17)

	Long-term			
	E	*M*	*L*	*K*
e	–0.735	–0.058	–0.186	0.092
	(–13.68)	(–1.27)	(–2.57)	(2.27)
m	0.002	–0.096	1.011	1.145
	(0.24)	(–1.17)	(3.95)	(6.28)
w	0.177	0.165	–0.668	0.217
	(2.22)	(4.77)	(–5.35)	(4.13)
q	0.215	0.221	0.179	–0.719
	(1.86)	(5.11)	(1.41)	(–6.19)
Y	0.832	0.932	0.904	1.243
	(0.92)	(1.23)	(1.05)	(1.28)

Bootstrapped t-ratios within parentheses.

spect to electricity, all of the flexible inputs are substitutes, in the short-term and in the long-term. Note that capital demand is fairly insensitive to changes in the price of electricity in the long term. Capital and electricity are weak substitutes. Labor and electricity are weak complements in both the short- and the long-term.

Berndt & Wood (1975) found that capital and energy are complements and that labor and energy are mild substitutes (U.S. manufacturing). Their results are based on a static factor demand model and time-series data.

Pindyck & Rotemberg (1983) used the same data set as Berndt & Wood (1975) and a model specification almost identical to ours. Their results suggest capital-energy complementarity and weak labor-energy substitutability in U.S. manufacturing.

The results indicate that the capital stock will decrease if the user cost of capital increases, while changes in output will have no significant effect on investments. These results contradict Lundgren (1998) where output is shown to strongly affect pulp and paper industry aggregate investments, while changes in the user cost of capital leave the capital stock unaffected. However, Lundgren's estimates are based on an integrated pulp and paper industry, different models[16], and aggregated time-series data. The qualitative results may differ because of these differences.

A study performed within a static model framework by Rehn (1995), applied to data from the Swedish printing paper industry, generate findings that are somewhat different to ours. The estimated elasticities differ in size, sign, and statistical significance. For example, Rhen estimate the own-price elasticity of capital to be positive and elastic (>1), which is the opposite of our result.[17] This implies that an increase in the user cost of capital generates investment in the printing paper and disinvestment in the pulp industry.

Conclusion

In this paper, we have shown how a dynamic factor demand model, that is consistent with rational expectations, can be estimated and used to study the effects of movements in the price of an input factor or changes in output level. The results generated from our empirical model provide detailed insight into the production structure of the Swedish pulp industry and into the relevance of adjust-

[16] An accelerator-type model and a neoclassical model. Adjustment costs are not explicitly considered.

[17] However, as Rehn points out, there are a few possible explanations for this. First, a plant's investment decision might be independent of the user cost of capital. Investments are made in the upward slope of the business cycle, which is normally when the cost of capital (interest rates) rises. Second, the investment decision and the actual investment may be separated in time.

ment costs associated with changes in the capital stock. The dynamic framework of the model gives short- and long-term elasticities, which enables us to analyze the effects over time.

We find no evidence supporting the belief that investments will be dampened if the price of electricity increases as a consequence of the nuclear phase-out. The capital demand elasticity with respect to the price of electricity is inelastic and positive, which implies a slight increase in pulp industry investment spending if the price of electricity increases. Our interpretation is that, in the long run, firms will replace some of its existing machinery with less energy-intensive machinery when the price of electricity rises.

One of the shortcomings of this paper is the assumption of exogenous output price. That is, we have not incorporated a first-order condition describing the optimal output level, given a market structure. To better capture the characteristics of the ''real world,'' a natural extension of the model would be to add information about the competitive environment in which the pulp industry plant operates. Another shortcoming is the assumption of competitive factor markets, especially pulpwood. At least during some periods, the pulp plants have had monopsony/ oligopsony power in the pulpwood market (Bergman & Brännlund, 1995).

As we mentioned in the results section, we are limited to using convex or quasi-convex adjustment cost functions. Apparently, our specified function, equation (17), does not capture the true nature of the adjustment costs in the pulp industry. Lumpy investment suggests scale economies or linearity, and a properly specified adjustment cost function (constant, linear or concave) would probably match the pulp industry investment behavior more accurately. We leave this for future research.

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