A Dynamic Factor Demand Model for the Swedish Pulp Industry*

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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 will arise when the capital stock is altered. The estimates are based on plant level panel data for the period 1972-1990. We find weak evidence of the presence of adjustment costs. All the estimated own price elasticities are negative and the empirical cost function have all the desired properties from theory. The result suggest that user cost of capital is a significant determinant of pulp industry investment, while output level is not. We also find that pulp industry investment is insensitive to variations in the price of electricity.

Keywords: factor demand, dynamic optimization, panel data, bootstrap.

JEL: C33, C61, D21.

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1. Introduction

The forest sector is one of the major industries in Sweden, and its well being is crucial for the whole economy to be in balance. Therefore, government policy and external shocks that affect the decision parameters for the forest industry will most probably also have substantial macroeconomic effects. Thus, it is important to acquire an understanding of how the 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 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. There is uncertainty about how this will affect energy-intensive industry, 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 the investment decision. This paper is an attempt to increase this understanding.

We use a dynamic model of the production structure with an adjustment process for quasi-fixed input factors. This enables us to analyze both short and long term elasticities. Studies of factor demand has been performed both in a static and a dynamic framework. The dynamic model framework can be divided into three sub groups: 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 process, or similar adjustment processes, for all input factors. These models lack theoretical underpinnings. In addition, interdependence between inputs are neglected. Second generation dynamic models incorporate interrelated factor demands into the firm's short run demand responses, but the role of economic theory is still limited, since economic factors affecting the time path of adjustment from short run to long run 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 run elasticities. The theoretical foundations of third generation dynamic models are mainly drawn from Lucas (1967a, b), Lau (1976) & McFad-

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

den (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 and 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 equations 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 if the empirical cost function has the properties of the theoretical cost function, constant returns to scale, the existence of adjustment costs for quasi-fixed inputs. We provide a complete description of the production technology in the pulp industry, including short term and long term demand elasticities consistent with rational expectations.

The following section contains the theoretical underpinnings of our approach. In section 3 we develop the empirical model by specifying functional forms for the restricted cost function and the adjustment cost function. In section 4 we present parameter estimates and demand elasticities together with econometric specification tests and tests of theoretical cost function curvature conditions. The estimation results and elasticities are presented in section 5. In section 6 we offer a short summary and a few concluding remarks.

2. Theory

Define a production function of a single output representative firm as

$$Y = F\left(\mathbf{v}, \mathbf{x}, \mathbf{z}, t\right), \tag{2.1}$$

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 costs of adjustment due to the necessity of devoting resources to change the input stock rather than producing output. The costs of adjustment are represented by the convex vector function

$$C(\mathbf{z},\mathbf{x},t) = \begin{bmatrix} C(z_{1,t},x_{1,t}) \\ C(z_{2,t},x_{2,t}) \\ \vdots \\ C(z_{l,t},x_{l,t}) \end{bmatrix}, \tag{2.2}$$

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

$$z_{j,t}{=}x_{j,t} - (1-\delta_j)x_{j,t-1} \;;\; j = 1,..,l \tag{2.3}$$

where z_j and x_j are the gross addition and level of the j^{th} stock respectively, and $0 \leq \delta_j < 1$ is the rate of depreciation for the j^{th}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 $\mathbf{p}$, $\mathbf{x}$, Y and t. The restricted cost function, G, is then formulated as

$$G_t = G(\mathbf{p},\mathbf{x},Y,t) \tag{2.4}$$

This function can be shown, under reasonable regularity conditions on F_t, 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,

$$\frac{\partial G_t}{\partial p_{i,t}} = v_{i,t} \tag{2.5}$$

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

The long-term dynamic problem facing the 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,

$$EPV(0) = \min_{\{\mathbf{x},\mathbf{z}\}} \varepsilon_t \left\{ \sum_{t=0}^{\infty} R_t \left[G\left(\mathbf{p},\mathbf{x},Y,t\right) + \sum_{j=1}^{l} a_{j,t}x_{j,t} + \sum_{j=1}^{l} C(z_{j,t},x_{j,t}) \right] \right\} \tag{2.6}$$

subject to a set of equations of motion, (2.3), which are driven by the control vector $\mathbf{z}$**,** and any constraints on stock or flow variables in the model. The time

t expectations operator is denoted ε_t, R_t is a discount factor and a_j is the user costs, or rental costs, of the j^{th} quasi-fixed factor.[2]

The optimization problem facing the firm is to find combinations among all the possible $G(\mathbf{p}, \mathbf{x}, Y, t)$, so that time paths of the state vector $\mathbf{x}$ and the control vector $\mathbf{z}$, minimizes 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 utilize the marginal condition, or 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.

3. Empirical 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, 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,

$$Y_{i,t} = F(K_{i,t}, L_{i,t}, E_{i,t}, M_{i,t}), \tag{3.1}$$

where i is a firm subscript and t is the time subscript. Assuming a cost minimizing behavior we write the restricted cost function as:

$$G_{i,t} = G\left(w_{i,t}, e_{i,t}, m_{i,t}, K_{i,t}, Y_{i,t}\right). \tag{3.2}$$

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

$$I_{i,t} = K_{i,t} - \left(1 - \delta_K\right) K_{i,t-1}. \tag{3.3}$$

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. The management of the firms is risk neutral, have rational expectations, and act on behalf on their shareholders to maximize the value of the firm by minimizing costs.

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

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

The cost minimizing variable factor demands are:

$$\begin{aligned} L_{i,t} &= \frac{\partial G_{i,t}}{\partial w_{i,t}}, \\ E_{i,t} &= \frac{\partial G_{i,t}}{\partial e_{i,t}} \text{ and} \\ M_{i,t} &= \frac{\partial G_{i,t}}{\partial m_{i,t}}. \end{aligned} \tag{3.4}$$

The stochastic dynamic optimization problem facing the firm is to solve,

$$\min_{\{K_t, I_t\}} \varepsilon_{i,t} \left\{ \sum_{t=0}^{\infty} R_t \left[G\left(w_{i,t}, e_{i,t}, m_{i,t}, K_{i,t}, Y_{i,t}\right) + q_{i,t} K_{i,t} + C\left(I_{i,t}, K_{i,t}\right) \right] \right\}, \tag{3.5}$$

subject to the equation of motion for capital, (3.3). The expectation operator, $\varepsilon_{i,t}$, for firm i is conditional on information available to firm management in period t. Time enter 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]

$$V\left(K_{i,t}, t\right) = g\left(K_{i,t}, I_{i,t}, t\right) + \varepsilon_{i,t} \left\{ R_t \left[V\left(K_{i,t+1}, t+1\right) \right] \right\}, \tag{3.6}$$

where

$$g\left(K_{i,t}, I_{i,t}, t\right) = G\left(w_{i,t}, e_{i,t}, m_{i,t}, K_{i,t}, Y_{i,t}\right) + q_{i,t} K_{i,t} + C\left(I_{i,t}, K_{i,t}\right). \tag{3.7}$$

By differentiating the value function with respect to K, we obtain the stochastic Euler equation ,

$$\frac{\partial G_{i,t}}{\partial K_{i,t}} + q_{i,t} + \frac{\partial C_{i,t}}{\partial K_{i,t}} + \varepsilon_{i,t} \left[R_t \left(\frac{\partial V\left(K_{i,t+1}, t+1\right)}{\partial K_{i,t}} \right) \right] = 0, \tag{3.8}$$

or

$$\frac{\partial G_{i,t}}{\partial K_{i,t}} + q_{i,t} + \frac{\partial C_{i,t}}{\partial K_{i,t}} + R_t \left(\frac{\partial C_{i,t+1}}{\partial K_{i,t}} \right) = \epsilon_{i,t+1}, \tag{3.9}$$

where $\epsilon_{i,t+1}$ 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.

[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.

Thus in 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,

$$\lim_{t\to\infty} \varepsilon_{i,t} \left[R_t \left(\frac{\partial G_{i,t}}{\partial K_{i,t}} + q_{i,t} + \frac{\partial C_{i,t}}{\partial K_{i,t}} \right) \right] = 0. \tag{3.10}$$

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

It should be pointed out that firms must also choose $Y_{i,t}$ to solve their intertemporal profit maximization problem.[5] This would require an additional first-order condition in our model. The choice of optimal $Y_{i,t}$ depend on such things as output market structure, costs of price adjustments, etc. Given assumptions about the firms market environment it would be possible to formulate this first-order condition and include it in the model to improve the efficiency of the empirical parameter estimates. However, if these assumptions are incorrect, the empirical model would generate inconsistent parameter estimates. By limiting ourselves to the cost-minimization problem, there is no need to rely on assumptions about market structure.

3.1. Model specification

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]

$$C_{i,t} = C\left(I_{i,t}, K_{i,t}\right) = \frac{\beta}{2} \left(\frac{I_{i,t}}{K_{i,t}} - \omega \right)^2 K_{i,t}. \tag{3.11}$$

This has the properties 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. That is, the rate of investment

[5] Note that as long as revenues solely depend 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 an further remark see for example Kennan (1979) and Meese (1980). This functional form is also used by Blundell et al (1992).

at which adjustment costs average zero. Marginal adjustment costs with respect to gross investment,

$$\frac{\partial C_{i,t}}{\partial I_{i,t}} = \beta \frac{I_{i,t}}{K_{i,t}} - \beta\omega \tag{3.12}$$

are linear in the observed rate of investment. The adjustment cost parameter is assumed to be non-negative, $\beta \geq 0$.[7]

When specifying the restricted cost function we use the translog form developed by Kmenta (1967) and introduced formally in a series of papers by 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. This functional form is highly general and non-homothetic. It is attractive because its flexible, in the sense that does not impose any restrictions on the substitution elasticities as in the case of Cobb-Douglas or CES technologies. We write the cost function for firm i in period t as:

$$\begin{aligned} \log G_{i,t} \quad = \quad & f_i + \alpha_0 + \log m_{i,t} + \alpha_1 \log\left(\frac{e_{i,t}}{m_{i,t}}\right) + \alpha_2 \log\left(\frac{w_{i,t}}{m_{i,t}}\right) \\ & + \alpha_3 \log K_{i,t} + \alpha_4 \log Y_{i,t} + \frac{1}{2}\gamma_{11}\left[\log\left(\frac{e_{i,t}}{m_{i,t}}\right)\right]^2 \\ & + \gamma_{12} \log\left(\frac{e_{i,t}}{m_{i,t}}\right) \log\left(\frac{w_{i,t}}{m_{i,t}}\right) + \gamma_{13} \log\left(\frac{e_{i,t}}{m_{i,t}}\right) \log K_{i,t} \\ & + \gamma_{14} \log\left(\frac{e_{i,t}}{m_{i,t}}\right) \log Y_{i,t} + \frac{1}{2}\gamma_{22}\left[\log\left(\frac{w_{i,t}}{m_{i,t}}\right)\right]^2 \\ & + \gamma_{23} \log\left(\frac{w_{i,t}}{m_{i,t}}\right) \log K_{i,t} + \gamma_{24} \log\left(\frac{w_{i,t}}{m_{i,t}}\right) \log Y_{i,t} \\ & + \frac{1}{2}\gamma_{33}(\log K_{i,t})^2 + \gamma_{34} \log K_{i,t} \log Y_{i,t} \end{aligned} \tag{3.13}$$

[7] The parameter β is the equivalent to the parameter in q-models of investment. A commonly used econometric specification of this model is

$$\left(\frac{I}{K}\right)_t = \omega + \beta^{-1} q_t + \varepsilon_t$$

which is derived from a maximization of present value of cash-flow in presence of the adjustment cost function specified in this paper. q_t is the ratio of the stock market's valuation of the firm's capital to its value at replacement costs.

$$+\frac{1}{2}\gamma_{44}(\log Y_{i,t})^2 + \lambda t.$$

The firm specific effects are represented by f_i and λ is rate of technical progress.[8] The cost share equations derived from the translog cost function are:

$$S_{L,i,t} = \frac{\partial \log G_{i,t}}{\partial \log w_{i,t}} = \alpha_2 + \gamma_{12} \log\left(\frac{e_{i,t}}{m_{i,t}}\right) + \gamma_{22} \log\left(\frac{w_{i,t}}{m_{i,t}}\right) + \gamma_{23} \log K_{i,t} + \gamma_{24} \log Y_{i,t}, \tag{3.14}$$

$$S_{E,i,t} = \frac{\partial \log G_{i,t}}{\partial \log e_{i,t}} = \alpha_1 + \gamma_{11} \log\left(\frac{e_{i,t}}{m_{i,t}}\right) + \gamma_{12} \log\left(\frac{w_{i,t}}{m_{i,t}}\right) + \gamma_{13} \log K_{i,t} + \gamma_{14} \log Y_{i,t}, \tag{3.15}$$

and by symmetry,

$$S_{M,i,t} \equiv 1 - S_{E,i,t} - S_{L,i,t}. \tag{3.16}$$

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

$$\frac{G_{i,t} S_{K,i,t}}{K_{i,t}} + q_{i,t} + \beta \left[\left(\frac{I_{i,t}}{K_{i,t}} - \omega\right)\left(1 - \frac{I_{i,t}}{K_{i,t}}\right) + \frac{1}{2}\left(\frac{I_{i,t}}{K_{i,t}} - \omega\right)^2 \right] \tag{3.17}$$

$$-\varepsilon_{i,t} \left\{ R_t \left[\beta (1-\delta) \left(\frac{I_{i,t+1}}{K_{i,t+1}} - \omega \right) \right] \right\} = 0,$$

which can be written more compactly as,

$$\frac{G_{i,t} S_{K,i,t}}{K_{i,t}} + q_{i,t} + f\left[\frac{\partial C_{i,t}}{\partial K_{i,t}}, R_t \left(\frac{\partial C_{i,t+1}}{\partial K_{i,t}}\right)\right] = \epsilon_{i,t+1}, \tag{3.18}$$

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

$$S_{K,i,t} = \frac{\partial \log G_{i,t}}{\partial \log K_{i,t}} = \alpha_3 + \gamma_{13} \log\left(\frac{e_{i,t}}{m_{i,t}}\right) + \gamma_{23} \log\left(\frac{w_{i,t}}{m_{i,t}}\right) + \gamma_{33} \log K_{i,t} + \gamma_{34} \log Y_{i,t}. \tag{3.19}$$

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

In the adjustment cost literature the 'normal rate' of investment parameter ω enters the empirical model in different ways. Chirinko (1987) treat ω as a given constant and set it equal to the depreciation rate δ; Hubbard et al. (1985) use a

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

fixed value of 0.1; and Whited (1992) estimated ω to approximately one, which must be considered unrealistic. We have chosen to follow Chirinko (1987) since 'normal rate' of investment should be close to the depreciation rate where the capital stock is in steady state.

The model can be used to derive formulas for 15 short-term 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 (during the long term time interval) when responding to immediate price changes. If prices evolve stochastically, the adjustment path 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 utilize the solution to a deterministic control problem to compute and estimate the long-term elasticities. Derivation of the two sets of elasticity formulas can be found in Appendix.

4. Data, estimation methods, and specification testing

To estimate the model we use a unique plant level panel data set. It contains cross section data from 22 pulp mills with annual observations from 1972 to 1990. The use of data on individual firms has several advantages compared to 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 individual firm level; heterogeneity across firms can be explicitly modeled. Using data at 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 that is used and how much it cost. 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 real financial cost of capital rates for the whole manufacturing industry.[9]

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

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

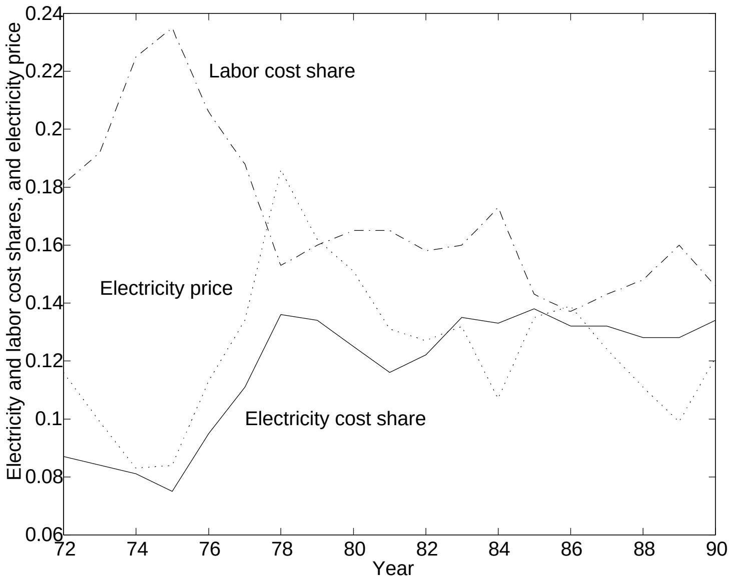

Figure 4.1: Cost shares and electricity price (base year=1981).

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 and ω are set to 0.0812.[10] Initially we have 418 observations (22 firms and 18 annual observations), but after removing a few obvious outliers and selecting only non-zero values of factor inputs, factor prices and gross investment, we are left with 278 observations.

As can be seen in figure 4.1 labor and electricity are clearly substitutes and they sum up to about 30 percent of the total cost. The pulpwood cost share is stable at about 70 percent and is therefore not included in the figure. The electricity price

, 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 value of investment ratio for machinery and buildings (0.9 and 0.1); r_m, r_b, δ_m and δ_b are real financial costs 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, $\delta = w_m\delta_m + w_b\delta_b$. The depreciation rate for machinery and buildings are 0.087 and 0.029 respectively ($w_m = 0.9$ and $w_b = 0.1$). The depreciation rates were derived for the Swedish forest industry for the period 1980-90 by SCB.

and the electricity cost share seems, at least during the seventies, to be closely related which is not surprising. On average, the pulp industry electricity price is .122 SEK/kwh, which is about half of the industry as a whole.

Firm specific fixed effects are assumed present in the restricted cost function due to 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 equation (3.13), (3.14), (3.15) and (3.17) is initially performed to estimate a set of parameters used to transform the variables 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.[11]

After transformation, equation (3.13), (3.14) and (3.15) are estimated simultaneously together with the restricted cost function (3.17), using a two-step instrumental variable, or Generalized Methods of Moments (GMM) estimator developed by Hansen (1982) and Hansen & Singleton (1982). The covariance matrix is made heteroscedastic-consistent (White, 1980). The cost function, share and Euler equation are assumed to hold in expectation to 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, and therefore 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 does not include any current variables appearing in any of the model equations. The first instrument set includes the following variables: a constant, $Y_{i,t-1}$, $K_{i,t-1}$, $L_{i,t-1}$, $E_{i,t-1}$, $M_{i,t-1}$, $q_{i,t-1}$, $w_{i,t-1}$, $e_{i,t-1}$, $m_{i,t-1}$, $R_{i,t-1}$, and the dummy variables. The second instrument set includes: a constant, $Y_{i,t-1}$, lagged aggregated Swedish forest industry investment, lagged consumer price in-

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

dex, 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. In *TABLE 1* we also report parameter estimates from a pooled (restricted model) data estimation. In this estimation the instrument sets are the same as above but we removed the lagged dummy variables.[12]

The elasticities are highly 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 asymtotically 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 can use a simple Chow test to test for firm specific effects.[15]

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 used to estimate the model. That is; (1) Since $G_{i,t}$ should be monotonically increasing in $w_{i,t}$, $e_{i,t}$, 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. (2) Since $G_{i,t}$ should be concave in the flexible input prices, the Hessian matrix of $G_{i,t}$ with respect to

[12] Time series for aggregated Swedish forest industry investment, 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 286 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 pseudodata and 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 and Tibshirani (1986) and (1993).

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

[15] That is, a F-test on firm dummies,

$$F_0 = \frac{(RRSS - URSS)/(N-1)}{URSS/(NT-N-K)} \overset{H_0}{\backsim} F_{N-1,N(T-1)-K}$$

where $RRSS$ is the restricted residuals sums of squares (pooled estimation) and $URSS$ is the unrestricted sums of squares (fixed effect estimation).

$w_{i,t}$, $e_{i,t}$, and $m_{i,t}$ must be negative semidefinite. (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 $\partial \log G_{i,t}/\partial \log Y_{i,t} = S_y$ (Chambers 1994, ch 2). Under the null firms technology exhibit constant returns to scale.

5. Results

Parameter estimates are shown in columns 1 to 4 in *TABLE 1*.

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. * Exceeds critical value.
[b] Under null $\Rightarrow$ constant returns to scale.

The adjustment cost parameter β, is only significant in the fixed effect model estimated with instrument set 1 (column 3). The point estimate is 0.22 which is about half of the Hansen and Lindberg (1997) estimate based on a panel data set of Swedish manufacturing firms. This result suggests that adjustment costs associated with changing the capital stock, is less important in the Swedish pulp industry than in the industry as a whole. However, the use of a convex adjustment cost function might not be appropriate due to the characteristics of the investment decision in the pulp industry. According to the firm level data investment expenditures follow a highly discontinous path with sharp spikes. This behavior does not fully comply with convexity in adjustment cost. The adjustment cost theory is based on the observation that aggregate investment data is continuous and smooth. The assumption of convexity will penalize lumpy investment while small subsequent investment is favored. This is probably why the pulp industry β is comparatively low. The structure of the minimization problem limits us to use only convex adjustment cost functions. On average, the adjustment cost is about 2 percent of investment. The distribution of the percentage adjustment cost is very skew, which might seem surprising. This is, again, a combined result of the structure of the data and the use of a convex adjustment cost function.

The J-statistic would suggest a rejection of the overidentifying restrictions at the 5 percent level in all four estimated models. Possible explanations for this would be misspecification of the cost function or irrational expectations behavior of the firms. We can not reject the presence of fixed effects in the cost function (column 3 and 4).

Property tests of the empirical cost function are presented in *TABLE 2*.

TABLE 2 - **COST FUNCTION PROPERTIES**[a]

	Pooled model		*Fixed effects model*	
	Inst set 1	*Inst set 2*	*Inst set 1*	*Inst set 2*
Hessian matrix test[b]	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

[a] The curvature conditions has to hold in every sample point.

[b] Negative semidefiniteness required.

Note that only the firm effects models have 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*. See Appendix for derivation of elasticity formulas.

TABLE 3 - **DEMAND ELASTICITIES (1989)**

	Short-term			
	E	M	L	
e	-0.708 (-16.43)	0.207 (4.23)	-0.160 (-2.25)	
m	0.821 (9.79)	-0.257 (-5.62)	0.774 (7.09)	
w	-0.114 (-1.62)	0.138 (4.34)	-0.614 (-4.97)	
K	-0.361 (-4.02)	-0.336(-5.64)	-0.249 (-1.49)	
Y	1.584 (1,64)	1.378 (1.37)	1.214 (1.17)	
	Long-term			
	E	M	L	K
e	-0.735 (-13.68)	-0.058 (-1.27)	-0.186(-2.57)	0.092 (2.27)
m	0.002 (0.24)	-0.096 (-1.17)	1.011 (3.95)	1.145 (6.28)
w	0.177 (2.22)	0.165 (4.77)	-0.668 (-5.35)	0.217 (4.13)
q	0.215 (1.86)	0.221(5.11)	0.179 (1.41)	-0.719 (-6.19)
Y	0.832 (0.92)	0.932 (1.23)	0.904 (1.05)	1.243 (1.28)

t-ratios within parentheses.

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.[16] 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 possibilities to vary the input of pulpwood given a certain production level. None of the elasticities, that are significantly different from zero in both short and long run, alternate signs. The elasticity estimates imply that, except labor demand with respect to electricity, all the flexible inputs are substitutes both in the short and long run. Note that capital demand is fairly non-sensitive to electricity price changes in the long run. Labor and electricity are mild complements both in the short and long term.

Berndt & Wood (1975) find that capital and energy are complements and that labor and energy are mild substitutes (US manufacturing). Their results are based on a static factor demand model and time series data. Pindyck & Rotemberg

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

(1983) use the same data set as Berndt & Wood (1975) and a model specification almost identical to ours. They also find capital-energy complementarity and mild labor-energy substitutability.

The results indicates that the capital stock will decrease if the user cost of capital increases, while changes in output will have no significant effect on investment. These results contradicts the results in Lundgren (1998), where output variables strongly affects pulp and paper industry aggregate investment while changes in user cost of capital leaves the capital stock unaffected.. However, Lundgrens estimates are based on a different models[17] and aggregated time series data. The qualitative results may differ due to these differences.[18]

In a study performed on a selected sample of the Swedish printing paper industry (Rehn, 1995), the estimated elasticities differs in size, sign and statistical significance. For example, Rhen estimates the own price elasticity of capital to be positive and elastic (>1)[19]. Although pulp and paper production processes may differ slightly, we believe that the main reason for the contradictory results is Rehns use of a non-dynamic model, which probably generates less accurate results.

6. 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 sudden 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 in the Swedish pulp industry, and the relevance of adjustment cost 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.

In our results we find no evidence supporting the widespread recognition that investment will drop significantly if the electricity price increase as a consequence of the nuclear phase out. The capital demand elasticity with respect to electricity

[17] An accelerator type model and the standard Jorgenson type neoclassical model.

[18] Aggregation of firm level data may result i loss of information.

[19] However, as Rehn point out, there are a few possible explanations for this. First, the plants investment decision might be independent of the user cost of capital. Investment are made in the upward slope of the buisness cycle, which is normally when the cost of capital (interest rate) rices. Second, the investment decision and the actual investment may be separetaded in time.

price is inelastic and positive, which implies a slight increase in pulp industry investment spending in case of an electricity price increase. Our interpretation is that, in the long run, firms will replace existing machinery with less energy intensive machinery, when the electricity price rises.

One of the shortcomings with 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 and Brännlund, 1995).

As we mentioned in the result section, we are limited to use convex or quasi-convex adjustment cost functions. Seemingly, our specified function, equation (3.11), does not capture the true nature of the adjustment costs in this industry. Lumpy investment suggest scale economies, and a properly specified concave adjustment cost function would probably match the pulp industry investment behavior more accurately.

Our model specification, and possible extensions to it, could easily be used to simulate changes in factor prices and output. We leave this for future research.

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