Effects of Increased Demand for Biofuels: A Dynamic Model of the Swedish Forest Sector*

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Abstract

In this paper, we estimate the dynamic effects on the forest sector of an increased demand for biofuels. This is done by developing a partial adjustment model of the forest sector that enables short, intermediate, and long run price elasticities to be estimated. It is relevant to study the effects of increased demand for biofuels as the Swedish government has committed to an energy policy that is likely to further increase the use of renewable resources in the Swedish energy system. Four subsectors are included in the model: the forest owners, who supply sawtimber, pulpwood and forest fuels; the sawmills which demand sawtimber; the pulp and paper industry which demands pulpwood; and the energy industry which demands forest fuels. The results show that the short run elasticities are fairly consistent with earlier studies and that sluggish adjustment in the capital stock is important in determining the short and intermediate run responses. Simulation shows that an increase in the demand for forest fuels has a positive effect on the equilibrium price of all the three types of wood, and a negative effect on the equilibrium quantities of sawtimber and pulpwood.

Key Words: Forest economics, Price elasticities, Long run, Energy sector.

JEL Classification: L73, L78, Q41, Q42.

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1 Introduction

In this paper, we study the dynamic effects on the Swedish forest sector of an increase in the demand for biofuels. To do this, we first develop and estimate a partial adjustment model of the forest sector. Next, we calculate the supply and demand elasticities for three central types of wood: sawtimber, pulpwood and forest fuels. In addition to the short run elasticities, the dynamic specification enables the calculation of the intermediate as well as the long run elasticities. Finally, the estimated model is used to simulate the short and long run effects of a government induced subsidy to increase the energy industry's demand for forest fuels.

The use of biofuels has been increasing steadily in Sweden during the last three decades. In 1970, less than 10 percent of the energy supply was derived from biofuels, however by 2003, the corresponding figure was almost 20 percent. In addition, in 1997, the Swedish government decided on a policy to convert the Swedish energy system towards being ecologically as well as economically sustainable. A number of long term environmental objectives were adopted in 1999. These include the aim of limiting Sweden's emissions of greenhouse gases. This objective was further confirmed in 2002, when the Swedish parliament passed a climate strategy implying that the Swedish emissions of greenhouse gases during the period 2008 to 2010 must be reduced to a level at least 4 percent lower than the 1990 levels. This is stricter than the requirements placed on Sweden by the EU burden-sharing agreement following the Kyoto protocol. However, indicators show that, based on the progress to date, the level of emissions will only be slightly lower in 2010 than in 1990. This means that in order to meet the four percent goal a continuous conversion of the energy system will presumably be needed, which is likely to imply a further increase in the use of renewable resources.

One of the main energy users is the district heating industry and, since the beginning of the 1980s, there has been an extensive substitution of biofuels for oil in this industry. Figure 1 shows how the energy supply from the district heating plants has almost tripled between 1970 and 2003. Biofuels have developed from constituting less than 1 percent of the inputs to more than 60 percent during the same period. An increasing demand for these fuels may have effects outside the energy industry, most notably in the forest sector. Today, a large part of the biofuels consists of residues from forestry and by-products from the sawmills and the pulp industry. However, a substantial rise in the use of renewable resources could mean that forest resources, with an alternative use (e.g., pulpwood), would have to be considered for energy purposes. This is likely to have an effect on other users of the forest, such as the sawmills and the pulp industry. It is, therefore, important to analyze how a more ecologically sustainable energy policy will affect the competition for forest resources.

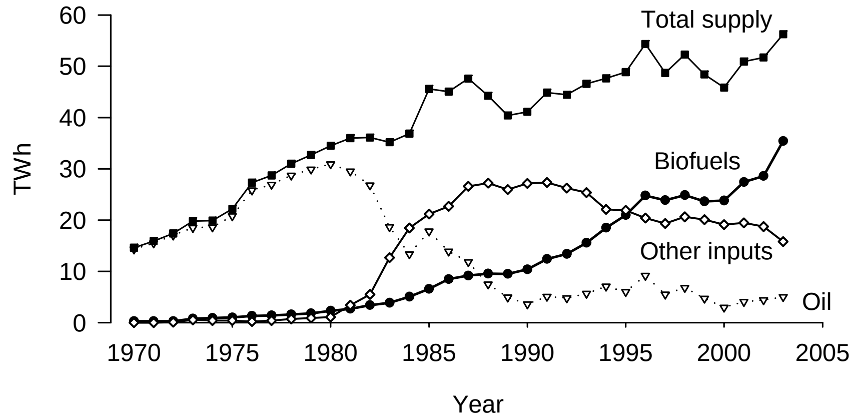

Figure 1: The supply of district heating in TWh, breakdown by energy source. As the use of oil has decreased since 1980, it has been replaced by biofuels as the major input in the generation of district heating. Other inputs are gas, coal, electricity, etc. (Author's own adaption of data from the Swedish Energy Agency.)

The Swedish forest sector has previously been studied by, among others, Brännlund and Kriström (1996) who compare partial and general equilibrium analysis when evaluating the welfare effects of taxes in the forest sector. They divide the forest sector into three subsectors: the forest owners, the sawmills, and the pulp and paper industry. The model is used as a starting point in Ankarhem, Brännlund and Sjöström (1999), who add the energy sector to study the short run effects of the demand for biofuels. In the analysis, they use a static model in which capital is assumed to be fixed. In a report for Sweden's ministry of industry in 2004 (hereafter referred to as FABS), a modified version of the model is used, where a lagged dependent variable is included to the demand equations, to obtain a dynamic specification. Other related studies of the Swedish forest sector are: Bergman and Brännlund (1995), who estimate the oligopsony power of the pulp and paper industry; Lundgren and Sjöström (1999), who estimate a dynamic factor demand model of the pulp industry; Brännlund and Kriström (2001), who evaluate the benefits and costs of stimulating the use of biofuels in the heating industry. Brännlund, Marklund and Sjöström (2004) and Sjöström (2004) evaluate market power on the market for woodfuel.

This paper contributes to the analysis of the Swedish forest sector in three ways: first, we incorporate capital adjustment costs for the three demand side industries. Short run elasticities can be derived using a static model. However, when the long run effects of, for instance, changes in input prices are being studied, one has to account for changes in the capital stock over time. A change in the variable inputs can be done with immediate effect, on the other hand, altering the capital stock to a desired optimal level may be associated with an adjustment cost. If the marginal cost is increasing with the amount of investment, it is more costly to adjust stocks quickly than slowly, which implies that a change in capital tends to be sluggish. Second, including adjustment costs and equations of motion for the capital stocks also enables us to evaluate the differences between short, intermediate and long run responses to price or policy changes. Third, the data set used in Ankarhem, Brännlund and Sjöström (1999) and FABS (2004) covers the period 1967-1994. The data set used in this paper is extended to also cover the years until 2003. These recent observations are highly relevant for the estimation since a considerable part of the substitution of fuels in the energy industry has occurred during this period.

The model developed in this paper is based on Ankarhem, Brännlund and Sjöström (1999), but the dynamics are mainly drawn from Thijssen (1994), and Lopez (1985), who use a partial adjustment approach to model the supply response and the dynamic factor demand for Dutch dairy farms and the Canadian food processing industry, respectively.

The rest of the paper is outlined as follows. In the following section, the theoretical model is developed. In section 3, the empirical model is specified and we derive the system of equations to be estimated. A description of the data and the estimation procedure is provided in section 4. In section 5, the estimated parameters are presented, and potential effects of a 10 percent increase in the demand for forest fuels are simulated. Finally, the empirical results are discussed in section 6.

2 Theory

The model of the forest sector is divided into four subsectors. It is depicted in Figure 2, where the supply side of the model consists of the forest owners who are assumed to have a multi-output production function that needs labor and capital, including forest inventory, to produce three different products; sawtimber, pulpwood and biofuels. The demand side of the model consists of three industries that have a single output production function. These are the sawmills which demand sawtimber, labor, electricity and capital to produce sawn wood; the pulp and paper industry which demands pulpwood, labor, electricity and capital to produce pulp and paper; and the energy producers who demand biofuels, labor, other fuels, and capital to produce energy. The model has thus four categories of actors who meet in three inter-related markets. To analyze their inter-relations, we first specify the profit functions of each sector. From these profit functions, we can derive the sectors' supply of products and their demand for production factors. By doing this, we are able to construct a system of equations characterizing each market,

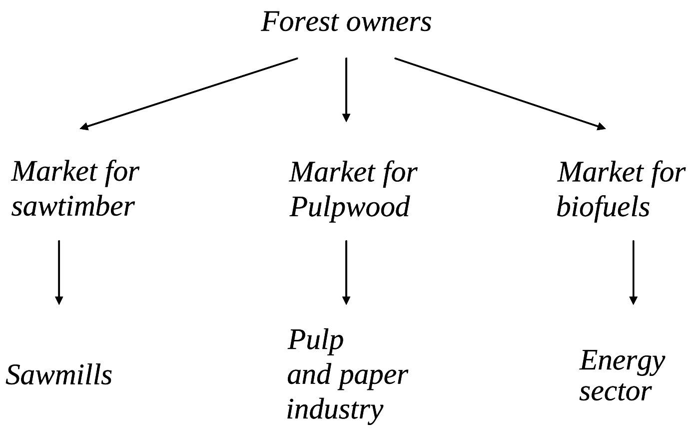

Figure 2: The forest owners supply sawtimber, pulpwood and woodfuels. The sawmills demand sawtimber, the pulp and paper industry demands pulpwood, and the energy sector demand woodfuels.

that includes a supply equation, a demand equation, and an equilibrium condition that imposes partial equilibrium. It then becomes possible to study, for instance, how an increase in the price of biofuels will affect, for example, the quantity of pulpwood sold, or the price of sawtimber. In this simplified description of the forest sector there are, however, flows that are not included. For instance, flows of wood chips from the sawmills to other parts of the traditional forest industries are not considered. The reason is, partly, an aim to keep the model simple, but also that much of theses quantities are not traded on the open market, at market prices.

In the short run, firms maximize their profit with respect to the variable input factor prices, conditioned on a fixed level of capital. The long run dynamic problem facing the firm, can be seen as maximizing the present value of the future stream of profits with respect to the capital stock and gross investments.

The assumption of capital being fixed in the short run is mainly due to the adjustment costs a firm is facing when changing the level of capital stock.[1] Adjustment costs basically mean that firms investing in, for instance new machinery, face costs in addition to the actual price of the purchased good. These costs could, e.g., arise from devoting resources to the installation of new machinery instead of producing output, or they could be learning costs stemming from inefficiency in operating the new machinery. The marginal cost of adjustment is often assumed

[1]It is reasonable to also model labor as a quasi fixed input. This would require adding three more equations to the system and, as the number of observations in the data set is limited, the simplification of only modelling the capital stock as a quasi fixed input is made. An alternative approach would be to estimate the actual Euler equation. However, this would only enable calculation of the short and the long run effects, and not the path of adjustment.

to be increasing, making it more costly to change the level of capital stock quickly rather than gradually over a longer period. Accordingly, the adjustment of firms' capital stocks tends to be sluggish. Overviews of adjustment costs in factor demand and investments are found in Hamermesh and Pfann (1996) and Chirinko (1993).

Assuming perfect competition, the representative firm's short run profit function can generally be written as a function of prices and the capital stock:

$$\pi = \pi(P, \mathbf{w}; k)$$

where P is the output price, $\mathbf{w}$ is a vector of variable input prices and k is the capital stock. Applying Hotelling's lemma to the profit function yields the conditional short run profit maximizing supply and demand functions, which are denoted y and x, respectively:

$$\begin{aligned} \frac{\partial \pi}{\partial P} &= y(P, \mathbf{w}; k) \\ \frac{\partial \pi}{\partial w} &= -x(P, \mathbf{w}; k) \end{aligned} \tag{1}$$

For simplicity, we assume that the forest owners' standing inventory of forest is fixed. For the sawmills, pulp industry, and the energy industry, however, we take into account the adjustment of the capital stocks. Their long run dynamic optimization problem then becomes:

$$\max \int_0^\infty \left(\pi\left(P, \mathbf{w}; k\right) - u\left(r + \delta\right) k - c(\dot{k})\right) e^{-rt} dt$$

where π is the profit function with the arguments defined as above. In the long run, capital is considered to be variable. We include, therefore, the asset price of capital, u, and the adjustment cost, c, in the maximization problem. The asset price of capital is a function of the real discount rate, r, plus the rate of depreciation of capital, δ, and the adjustment cost is a function of investment, the change in capital, $\dot{k}$. Applying Euler's equation of the calculus of variation (cf. Chiang, 1992), the first order condition with respect to capital for the problem is:

$$\pi_k = u(r + \delta) + rc_{\dot{k}} - c_{\dot{k}\dot{k}}\ddot{k}$$

In the long run, however, we assume that the capital stock fully adjusts to its optimal level, and the investments, $\dot{k}$, as well as the change in investments, $\ddot{k}$, will, therefore, be zero. If we, in addition, assume that the adjustment costs are zero when no investment takes place, the first order condition becomes:

$$\pi_k(k^*, \dot{k} = 0) = u(r + \delta) \tag{2}$$

where k^* denotes the optimal long run capital stock. The expression above is the static condition that the marginal return to capital should be equal to the user cost of capital, but it is now required to hold at every time period t. Next we want to derive a demand function for capital from this expression. To do this we follow Lucas (1967), and approximate equation (2) linearly around the long run optimal capital stock, k^*, obtaining a second order differential equation. If the equation is solved for its stable root, λ, the following equation is obtained:

$$\dot{k} = \lambda(k^* - k) \tag{3}$$

where $\lambda = -1/2\{r - (r^2 - 4\pi_{kk}/c_{\dot{k}\dot{k}})^{1/2}\}$. Eq. (3) expresses the optimal net investment as a fraction of the difference between the optimal long run capital stock and the actual capital stock level. For estimation purposes, it is more convenient to write the investment function in its discrete form since annual data will be used in the analysis. This enables us to write the following demand equation for capital:

$$k_{t+1} = \lambda k_t^* + (1 - \lambda)k_t \tag{4}$$

An important property of the equation is that the stable root should have a value between zero and one, where zero implies no adjustment and one implies full adjustment in period t. Considering equations (1) - (4), we now have the short run output supply and input demand equations for the forest owners. We also have the short run output supply and input demand equations as well as the capital demand equations for the sawmills, pulp industry and the energy industry. Together they form a set of behavioral equations for the representative firm that are necessary for our analysis and the derivation of elasticities. For estimation purposes, however, we only derive the forest owners' output supply equations for the three types of forest and the demand equation for the type of forest used as intermediate input in the sawmills, pulp industry and the energy industry, as well as the capital demand equations for the sawmills, pulp industry and the energy industry. Altogether, we have therefore three output supply equations, three intermediate input demand equations and three capital demand equations in our system.

3 Empirical specification

To estimate the model and to calculate the elasticities, we need to specify the functional forms of π and c for each of the industries. Quadratic functions are chosen as approximations of the underlying true functions. Using the quadratic function, implies a local second order approximation of an arbitrary function which also means a linear approximation of the first order conditions. In the following, super index f, s, p and b indicate the forest owners, sawmills, pulp industry and energy industry, respectively. For simplicity, time indexation is only used when necessary. The adjustment cost functions may then be specified as $c^s = 0.5\beta_{adj}(\dot{k}^s)^2$, $c^p = 0.5\gamma_{adj}(\dot{k}^p)^2$, and $c^b = 0.5\delta_{adj}(\dot{k}^b)^2$, respectively.

The quadratic short run profit function for the forest owners, π^f, is written

$$\pi^f = \alpha_0 + \sum_i \alpha_i w_i^f + 0.5 \sum_i \sum_j \alpha_{ij} w_i^f w_j^f + \alpha_k k^f + \sum_i \alpha_{ki} k^f w_i^f + 0.5\alpha_{kk}(k^f)^2, \qquad (5)$$

where $i, j = s, p, b, l$. Then w_s^f, w_p^f, w_b^f denote the output price of sawtimber, pulpwood, and biofuels, respectively. The w_l^f denotes the input price of forest labor, while k^f is the capital. For the sawmill, pulp, and the energy industry (the demand side), the respective profit function will be

$$\begin{aligned} \pi^s = \beta_0 + \beta_P P^s + \textstyle\sum_i \beta_{Pi} P^s w_i^s + \beta_{Pk} P^s k^s + 0.5\beta_{PP}(P^s)^2 + \sum_i \beta_i w_i^s \\ +0.5 \textstyle\sum_i \sum_j \beta_{ij} w_i^s w_j^s + \beta_k k^s + \sum_i \beta_{ki} k^s w_i^s + 0.5\beta_{kk}(k^s)^2, \ i, j \ &= \ s, e, l \end{aligned} \qquad (6)$$

$$\begin{aligned} \pi^p = \gamma_0 + \gamma_P P^p + \textstyle\sum_i \gamma_{Pi} P^p w_i^p + \gamma_{Pk} P^p k^p + 0.5\gamma_{PP}(P^p)^2 + \sum_i \gamma_i w_i^p \\ +0.5 \textstyle\sum_i \sum_j \gamma_{ij} w_i^p w_j^p + \gamma_k k^p + \sum_i \gamma_{ki} k^p w_i^p + 0.5\gamma_{kk}(k^p)^2, \ i, j \ &= \ p, e, l \end{aligned}$$

$$\begin{aligned} \pi^b = \delta_0 + \delta_P P^b + \textstyle\sum_i \delta_{Pi} P^b w_i^b + \delta_{Pk} P^b k^b + 0.5\delta_{PP}(P^b)^2 + \sum_i \delta_i w_i^b \\ +0.5 \textstyle\sum_i \sum_j \delta_{ij} w_i^b w_j^b + \delta_k k^b + \sum_i \delta_{ki} k^b w_i^b + 0.5\delta_{kk}(k^b)^2, \ i, j \ &= \ b, e, l \ , \end{aligned}$$

where the subscripts s, p, b, e, l refer to the inputs sawtimber, pulpwood, biofuels, energy and labor, respectively. Electricity is used as the energy input in the sawmill and the pulp industry, and oil is used as the energy input (other than forest fuels) in the district heating plants. For the sawmill industry, we have therefore that P^s is the price of the output, sawn wood, and that the price of the intermediate input sawtimber is w_s. The energy and labor prices are denoted w_e^s and w_l^s respectively, while capital is k^s. For the pulp industry, the price of the final product pulp is P^p, and the prices of the input factors pulpwood, energy and labor are denoted w_p, w_e^p and w_l^p respectively. Capital is denoted k^p. The price of district heating from the energy industry is denoted P^b, and w_b, w_e^b, w_l^b are the prices of biofuels, oil and labor. The capital in the energy industry is k^b.

To ensure that the profit functions are linearly homogenous in prices, all prices are normalized with respect to the producer price index, PPI. Since we do not estimate the entire demand system for each industry, the PPI may be seen as the price of an input "other". Here, the forest sector is assumed to be small in relation to total labor and electricity demand, implying that their prices can be treated as exogenous. On the other hand, we assume that the forest owners' supply of sawtimber, pulpwood and biofuels are used entirely by the sawmill, pulp and energy industries. This implies that their quantities and prices are determined by the equilibrium between supply and demand. By applying Hotelling's lemma to the forest owners' profit function, we obtain the forest owners' supply of forest and the demand for labor. For estimation purposes, we only derive the supply equations:

$$\begin{aligned} y_s &= \alpha_s + \alpha_{ss} w_s^f + \alpha_{sp} w_p^f + \alpha_{sb} w_b^f + \alpha_{sl} w_l^f + \alpha_{sk} k^f \\ y_p &= \alpha_p + \alpha_{ps} w_s^f + \alpha_{pp} w_p^f + \alpha_{pb} w_b^f + \alpha_{pl} w_l^f + \alpha_{pk} k^f \\ y_b &= \alpha_b + \alpha_{bs} w_s^f + \alpha_{bp} w_p^f + \alpha_{bb} w_b^f + \alpha_{bl} w_l^f + \alpha_{bk} k^f \ , \end{aligned} \tag{7}$$

where y_s is the supply of sawtimber, y_p and y_b are the supply of pulpwood and biofuels respectively. By applying Hotelling's lemma to the profit functions of the sawmills, the pulp industry and the energy industry, we obtain the supply functions for the output products and the demand functions for the intermediate inputs. For these industries we only derive the demand equations:

$$\begin{aligned} x_s &= -\beta_s - \beta_{sP} P^s - \beta_{ss} w_s^f - \beta_{se} w_e^s - \beta_{sl} w_l^s - \beta_{sk} k^s \\ x_p &= -\gamma_p - \gamma_{pP} P^p - \gamma_{pp} w_p^f - \gamma_{pe} w_e^p - \gamma_{pl} w_l^p - \gamma_{pk} k^p \\ x_b &= -\delta_b - \delta_{bP} P^b - \delta_{bb} w_b^f - \delta_{be} w_e^b - \delta_{bl} w_l^b - \delta_{bk} k^b \ , \end{aligned} \tag{8}$$

where x_s is the sawmills' demand for sawtimber, x_p is the pulp industry's demand for pulpwood and x_b is the energy industry's demand for biofuels. Using the static condition that the marginal return to capital equals the user cost of capital, eq. (2), for each industry, we may obtain the long run optimal capital stock from the profit function. Substituting the expression for the optimal long run capital stock into eq. (4) for each of the demand side industries gives the following empirical demand equations for capital:

$$\begin{aligned} k_{t+1}^s &= \frac{\lambda^s}{\beta_{kk}} [u_t^s - \beta_k - \beta_{kP} P_t^s - \beta_{ks} w_{s,t}^f - \beta_{ke} w_{e,t}^s - \beta_{kl} w_{l,t}^s] + (1-\lambda^s) k_t^s \\ k_{t+1}^p &= \frac{\lambda^p}{\gamma_{kk}} [u_t^p - \gamma_k - \gamma_{kP} P_t^p - \gamma_{kp} w_{p,t}^f - \gamma_{ke} w_{e,t}^p - \gamma_{kl} w_{l,t}^p] + (1-\lambda^p) k_t^p \\ k_{t+1}^b &= \frac{\lambda^b}{\delta_{kk}} [u_t^b - \delta_k - \delta_{kP} P_t^b - \delta_{kb} w_{b,t}^f - \delta_{ke} w_{e,t}^b - \delta_{kl} w_{l,t}^b] + (1-\lambda^b) k_t^b \ . \end{aligned} \tag{9}$$

Combining equations (7-9), we have the complete system of empirical equations to be estimated. From this system, we can derive the responses in demand and supply to price changes, not only for the short run, but also for the intermediate and the long run. Short run elasticities are calculated given that only the variable inputs change, i.e. capital is fixed, while the long run elasticities apply when adjustment in the capital stock also takes place.

The forest owners' short run responses in output supply to changes in the product prices are obtained from $\partial y_i / \partial w_j = \alpha_{ij}$, where α is the immediate effect for $i = s, p, b$ and $j = s, p, b, l, k$. For the sawmills, pulp industry and the energy industry, the short run responses of their respective intermediate input demand to changes in any variable input factor price are obtained from $\partial x_s / \partial w_j = -\beta_{sj}$, $\partial x_p / \partial w_j = -\gamma_{pj}$, $\partial x_b / \partial w_j = -\delta_{bj}$, respectively, where

$j = s, e, l$ for the sawmills, $j = p, e, l$ for the pulp industry, and $j = b, e, l$ for the energy industry. These responses constitute the first of the right hand side terms for the intermediate run responses of the variable input demand:

$$\frac{\partial x_i^{IR}}{\partial w_j} = \frac{\partial x_i^{SR}}{\partial w_j} + \frac{\partial x_i^{SR}}{\partial k}\frac{\partial k^{IR}}{\partial w_j}, \tag{10}$$

where $j = s, e, l$ for $i = s$, $j = p, e, l$ for $i = p$ and $j = b, e, l$ for $i = b$. The intermediate response is equal to the short run response plus the response induced by the change in capital due to the variation in the price originally changed. If we, by intermediate run, mean three years, we can calculate the intermediate run variation in capital by taking the derivative of the difference equation of capital resulting from the successive substitution of the expression for k_{t+1}, eq. (4), into the equation for k_{t+2} proceeding up to k_{t+3}. This exercise yields the following expression:

$$\frac{\partial k^{3years}}{\partial w_j} = \lambda\frac{\partial k^*}{\partial w_j} + (1-\lambda)\lambda\frac{\partial k^*}{\partial w_j} + (1-\lambda)^2\lambda\frac{\partial k^*}{\partial w_j},$$

where $\partial k^*/\partial w_j$ is obtained from the expression for the optimal capital stock. Collecting terms and rearranging gives the following intermediate run responses for the sawmills, the pulp industry and the energy industry:

$$\begin{aligned} \frac{\partial x_s^{IR}}{\partial w_j} &= -\beta_{sj} + \frac{\beta_{sk}\beta_{kj}}{\beta_{kk}}\left(\lambda^s + (1-\lambda^s)\lambda^s + (1-\lambda^s)^2\lambda^s\right) \\ \frac{\partial x_p^{IR}}{\partial w_j} &= -\gamma_{pj} + \frac{\gamma_{pk}\gamma_{kj}}{\gamma_{kk}}\left(\lambda^p + (1-\lambda^p)\lambda^p + (1-\lambda^p)^2\lambda^p\right) \\ \frac{\partial x_b^{IR}}{\partial w_j} &= -\delta_{bj} + \frac{\delta_{bk}\delta_{kj}}{\delta_{kk}}\left(\lambda^b + (1-\lambda^b)\lambda^b + (1-\lambda^b)^2\lambda^b\right) \end{aligned} \tag{11}$$

where $j = s, e, l$ for the sawmills, $j = p, e, l$ for the pulp industry, and $j = b, e, l$ for the energy industry. The long run responses can be derived from eq. (10), using the long run demand for capital instead of the intermediate run demand. This is equal to using eq. (11), setting $\lambda = 1$. The long run response of the demand for capital is equal to the response of the optimal capital stock, because, in the long run, the actual and the optimal capital stocks are the same.

4 Data and estimation

The sample used to estimate the system consists of annual time series data, 1968 to 2003, aggregated to sector level. Most of the data are collected from Swedish official statistics, mainly SOS Industry, but also from the Yearbook of Forest Statistics and Energy in Sweden. Descriptive statistics of the data set are displayed in Table 1. Gross fellings are used as series of sold quantities for sawtimber and pulpwood. The forest owners supply forest fuels to households as well as to the district heating plants. These two series are combined to obtain the equilibrium

Table 1: Descriptive Statistics. Observations for the time period 1968-1999 give a sample size of 36 observations.

Sector	Variable	Unit	Mean	St. Dev.	Minimum	Maximum
Forestry	y_s	M.m^3	25.4	4.8	16.0	34.2
	y_p	M.m^3	25.3	3.7	20.5	36.9
	y_b	M.m^3	5.9	4.6	1.3	16.0
	w_s	SEK/m^3	475.1	79.6	372.7	683.0
	w_p	SEK/m^3	307.6	52.6	218.2	431.4
	w_b	SEK/m^3	336.7	76.5	212.5	491.6
	w_l	SEK/m^3	137.1	31.3	88.4	190.1
	k	M.m^3	2727.1	239.6	2370.0	3174.0
Sawmill Ind.	P	SEK/m^3	1797.7	187.6	1464.9	2306.6
	w_e	SEK/MWh	414.8	82.2	221.4	578.6
	w_l	SEK/hour	94.4	12.3	71.0	117.0
	k	B.SEK	23.2	6.2	9.7	31.2
	u	Index	1.4	0.6	0.2	2.8
Pulp Ind.	P	SEK/Kkg	4065.6	692.1	3081.6	5861.2
	w_e	SEK/MWh	245.4	52.0	176.8	462.2
	w_l	SEK/hour	112.5	17.5	74.8	142.6
	k	B.SEK	44.6	10.3	21.5	53.5
	u	Index	1.1	0.7	-0.6	2.3
Energy Ind.	P	SEK/MWh	308.3	70.6	197.7	429.4
	w_e	SEK/MWh	136.1	57.5	38.4	248.1
	w_l	SEK/hour	110.7	15.4	80.6	146.4
	k	B.SEK	311.3	93.3	143.2	440.0
	u	Index	1.2	0.6	-0.3	2.3

Notes: The output prices and the supplied quantities in the forestry sector are also included as prices of the variable inputs and demanded quantities for the respective demand side sectors. All prices are expressed at the 2003 level.

quantity of forest fuels. All the prices are normalized with respect to the producer price index. The output prices in the forestry sector are used as intermediate factor prices in the respective demand side industries. A large part of the forest fuels is chopped into wood chips, therefore, we use the price of wood chips for forest fuels in general. For sawmills and the pulp industry, export prices are used as output prices, whereas an implicit output price is used for the energy industry. This is calculated from the supply of district heating measured in value and in quantity. Because of the lack of original data for the years 1968 to 1973, the output price for energy is backcasted for the period. The predicted values from an AR(1) estimation are used for this, in order to avoid introducing collinearity with other variables in the system. The wages in forestry are approximated by the cutting cost per cubic meter, which means that costs other than labor are also included. From the cost for labor and the number of hours worked, an implicit price for labor is calculated for each of the demand side sectors. While the main energy input is assumed to be electricity for the sawmills and the pulp industry, oil is used as an energy input in addition to forest fuels, for the energy industry. The electricity and oil prices are calculated implicitly from industry specific costs and quantities. The standing inventory of timber is used as the real capital stock for the forest owners. For the sawmills and the pulp industry, the real capital stocks, measured as the value of machines and buildings, are available for the years prior to 1996. Capital stocks are also available for the period from 1997 to 2003, but the series for the two periods are not directly comparable. Since we are interested in the development rather than the level of the capital stocks, the latter series are shifted and linked to the former. We have not obtained a good estimate of the capital stock for the district heating plants, therefore, a smoothed series of the capital stock for the entire energy industry is used as a proxy to capture the general development of the capital stock for the heating plants. In calculating the user cost of capital,[2] q is an investment price index obtained as the difference between the gross investment series in current and fixed prices and r is the real interest rate. The capital depreciation rate, δ, is calculated from the perpetual inventory formula, solving for depreciation.

When estimating equations (7)-(9), we assume that the observed values of the short run input demand, the output supply and the capital demand are stochastically distributed around their optimal levels. Accordingly, an additive error term, that is assumed to be normally distributed with a zero mean and variance σ^2, is appended to each equation. The endogenous variables in the system are the quantities of sawtimber, pulpwood, biofuels, as well as their prices, and the capital stocks in period $t+1$. The rest of the variables are considered exogenous. A trend variable is added to the demand equations for pulpwood and forest fuels. If the explanatory variables are uncorrelated with the error term, the SUR approach is an appropriate estimation technique for the system as it makes use of the cross equation correlations of the disturbances. However, because of the presence of right hand side endogenous variables, an instrumental variable method is needed for estimation. The Three Stage Least Squares (3SLS) is chosen as the estimator, using all the exogenous variables in the system as instruments (cf. Greene, 2003). Heteroskedasticity is accounted for by using White's standard errors.

5 Results

5.1 Estimation results

One of the original 36 observations is lost when the capital stock is leaded, so there are 35 observations left for the estimation of the model. Prior to estimating the system, six symmetry restrictions implied by economic theory are imposed. This minimizes the number of parameters to be estimated. There are 62 remaining parameters and 43 of them are significant at the 5

[2] The user cost of capital is calculated using the formula: $u = \frac{q}{PPI}(r+\delta)$.

Table 2: Parameter estimates (3SLS)

Forestry								
Sawtimber			Pulpwood			Forest fuels		
Par.	Est.	s.e.	Par.	Est.	s.e.	Par.	Est.	s.e.
α_s	26.297	9.967*	α_p	54.557	13.476*	α_b	-10.121	4.850*
α_{ss}	0.016	0.007*	α_{ps}	-0.023	0.006*	α_{bs}	-0.001	0.003
α_{sp}	-0.023	0.006*	α_{pp}	0.058	0.008*	α_{bp}	-0.008	0.006
α_{sb}	-0.001	0.003	α_{pb}	-0.008	0.006	α_{bb}	-0.014	0.006*
α_{sl}	-0.086	0.014*	α_{pl}	-0.044	0.013*	α_{bl}	-0.029	0.014*
α_{sk}	0.004	0.003	α_{pk}	-0.010	0.003*	α_{bk}	0.010	0.001*
Sawmill Ind.			Pulp Ind.			Energy Ind.		
Par.	Est.	s.e.	Par.	Est.	s.e.	Par.	Est.	s.e.
β_s	-38.058	3.256*	γ_p	-32.502	5.697*	δ_b	-9.863	1.325*
β_{sP}	-0.004	0.002*	γ_{pP}	-0.002	0.0005*	δ_{bP}	-0.011	0.003*
β_{ss}	0.011	0.007*	γ_{pp}	0.005	0.013	δ_{bb}	0.004	0.001*
β_{se}	0.050	0.005*	γ_{pe}	0.059	0.016*	δ_{be}	0.015	0.003*
β_{sl}	-0.188	0.028*	γ_{pl}	-0.083	0.036*	δ_{bl}	0.079	0.008*
β_{sk}	0.473	0.093*	γ_{pk}	-0.113	0.106	δ_{bk}	0.158	0.009*
β_k	124.639	97.356	γ_{pt}	0.406	0.157*	δ_{bt}	-1.802	0.083*
β_{kP}	0.015	0.050	γ_k	14.898	70.315	δ_k	154.330	31.378*
β_{ks}	0.473	0.093*	γ_{kP}	0.021	0.036	δ_{kP}	-0.004	0.036
β_{ke}	-0.511	0.222*	γ_{kp}	-0.113	0.106	δ_{kb}	0.158	0.009*
β_{kl}	0.746	0.574	γ_{ke}	0.727	1.554	δ_{ke}	0.208	0.056*
β_{kk}	-8.214	3.585*	γ_{kl}	0.572	1.375	δ_{kl}	0.209	0.133
β_{adj}	646.581	245.829*	γ_{kk}	-5.854	12.015	δ_{kk}	-0.388	0.066*
λ^s	0.102	0.022*	γ_{adj}	336.605	735.524	δ_{adj}	358.290	43.784*
			λ^p	0.121	0.021*	λ^b	0.023	0.001*

Note: The * denote significance at the five percent level.

percent level. The estimated coefficients and the standard errors are presented in Table 2.

While all the adjustment cost parameters, β_{adj}, γ_{adj} and δ_{adj}, are positive, they are significantly different from zero for the sawmills and the heating plants. For these two industries, we may, therefore, statistically conclude that the adjustment costs play an important role in determining the short and intermediate run responses. The adjustment process is reflected in the size of the adjustment function parameters which were estimated as λ^s= 0.102 for the sawmills, λ^p= 0.121 for the pulp industry and λ^b= 0.023 for the energy industry. One tailed t-tests show that they are all significantly less than 1, so we may conclude, statistically, that there is an inertia in the adjustment process. The low value of the adjustment parameters suggests substantially less than full adjustment of the capital to its optimal level within one period. Tests for autocorrela-

Table 3: Short-run supply elasticities for the forest owners.

	Sawtimber		Pulpwood		Forest fuels	
Elast.	Est.	s.e.	Est.	s.e.	Est.	s.e.
η_{y,w_s}	0.18	0.08	-0.35	0.08	-0.02	0.06
η_{y,w_p}	-0.16	0.04	0.51	0.07	-0.12	0.08
η_{y,w_b}	-0.01	0.02	-0.07	0.05	-0.19	0.08
η_{y,w_l}	-0.25	0.04	-0.17	0.05	-0.18	0.08
$\eta_{y,k}$	0.38	0.24	-1.21	0.42	1.99	0.26

Notes: Elasticities evaluated at the 2003 price level. The standard errors are calculated using the delta method.

tion[3] show that there is serial correlation in the system and the variance of the parameters may, therefore, be underestimated. The goodness of fit measure, the adjusted R^2, varies over the equations with the lowest value of 0.55 for the pulpwood supply equation. The capital demand equations are the best fitted with values of 0.99. This is mainly due to the inclusion of the lagged capital in the respective equations.

The efficiency of the estimation could be improved if more observations were included in the data set. Using annual time series is not optimal for this type of study since it yields few observations, but also because historical data is then used to evaluate the presence and to simulate the future. It would therefore be preferable to have access to a panel data set with perhaps fewer years but with several different plants.

Next, we turn to the estimated elasticities. Table 3 shows the own, and cross price supply elasticities for the forestry. The own price supply elasticities have the expected positive sign for sawtimber and pulpwood. However, they are negative for the supply of forest fuels, which is not consistent with economic theory. The cross price elasticities are negative for the three types of wood, indicating that the they are all substitutes for each other. The cutting costs have a negative effect on the supply, and the standing forest inventory has a positive effect.

Table 4 shows the demand elasticities in the short, intermediate (three years) and the long run. All three intermediate input factors respond positively to the their respective final good output price. Further, all the own price elasticities have the expected negative sign and they satisfy the LeChatelier principle. This implies that the elasticities will be greater in absolute values as the capital stock adjusts to its optimal level, i.e., the intermediate run elasticity will exceed the short run elasticity and the long run elasticity will exceed the intermediate run

[3] The partial autocorrelation function is used to determine the order of autoregression in each equation. The results indicate autocorrelation in the demand for pulpwood and for biofuels as well as in the capital demand equations for the pulp and the energy industries.

Table 4: Elasticities for Sawmills, Pulp Industry and Energy Industry.

		Short run		Three years		Long run	
Sector	Elast.	Est.	s.e.	Est.	s.e.	Est.	s.e.
Sawmill Ind.	$\varepsilon_{x,p}$	0.19	0.12	0.18	0.12	0.15	0.18
	ε_{x,w_s}	-0.13	0.08	-0.22	0.08	-0.45	0.12
	ε_{x,w_e}	-0.84	0.08	-0.71	0.06	-0.34	0.10
	ε_{x,w_l}	0.64	0.10	0.60	0.09	0.50	0.11
	$\varepsilon_{x,k}$	-0.43	0.08				
Pulp Ind.	$\varepsilon_{x,p}$	0.19	0.06	0.21	0.06	0.24	0.09
	ε_{x,w_p}	-0.05	0.12	-0.06	0.12	-0.07	0.13
	ε_{x,w_e}	-1.04	0.27	-0.96	0.21	-0.79	0.15
	ε_{x,w_l}	0.44	0.19	0.46	0.20	0.50	0.22
	$\varepsilon_{x,k}$	0.22	0.21				
Energy Ind.	$\varepsilon_{x,p}$	0.30	0.08	0.30	0.08	0.33	0.36
	ε_{x,w_b}	-0.06	0.03	-0.12	0.02	-0.84	0.16
	ε_{x,w_e}	-0.19	0.03	-0.27	0.04	-1.16	0.16
	ε_{x,w_l}	-0.72	0.07	-0.77	0.08	-1.42	0.39
	$\varepsilon_{x,k}$	-4.35	0.25				

Notes: Elasticities evaluated at the 2003 price level. The standard errors are calculated using the delta method.

elasticity. However, the cross price elasticities and the elasticities with respect to capital do not need to obey this restriction. They are allowed instead to overshoot (Thijssen, 1994), which means that their short run values may be the greatest in magnitude. The cross price elasticities are negative with respect to the energy price for all three industries, positive with respect to wages in the sawmills and the pulp industry, and negative in the energy industry. Capital appears to be substitute for sawtimber and for biofuels, and it seems to be a complement to pulpwood. Overshooting occurs for four elasticities: the output price, the energy price and wages in the sawmill industry, as well as for wages in the pulp industry. From the standard errors presented in Tables 3 and 4, we see that all but one of the output supply elasticities are significantly less than 1, and all but one of the own price demand elasticities are significantly greater than -1, indicating an inelastic response to price changes. The exceptions are the long run output supply and the own price demand elasticities for the energy industry, for which unit elastic response cannot be rejected.

In the study by Ankarhem, Brännlund and Sjöström (1999), forest fuels and pulpwood are found to be complements to each other. The results in this study seem to support the findings in FABS (2004) which suggest, instead, that they are substitutes for each other. An elasticity that stands out is the own price supply elasticity for forest fuels, which is negative and hard to find plausible. Instead, it is positive in both the study by Ankarhem, Brännlund and Sjöström (1999) and in FABS (2004), although it is very close to zero in the former.

Turning to the sawmill industry, the elasticities presented here, all have the same sign as in the previous studies, including Brännlund and Kriström (1996). For the pulp industry, the elasticity with respect to the output price is fairly in line with previous studies. An exception is Lundgren and Sjöström (1999), who find a short run elasticity greater than unity when using an Euler equation approach to study the dynamic factor demand in the pulp industry. For the energy industry, the elasticities with respect to the output price and the own price support the results found in FABS (2004). The own price responses in Ankarhem, Brännlund and Sjöström (1999), however, do not have the expected sign for either the pulp or the energy industry.

5.2 Simulation

To illustrate the effects of a government induced policy to stimulate the use of biofuels in district heating plants, we simulate a subsidy that increases the demand for forest fuels by 10 percent. We start by replacing the negative own price supply elasticity for forest fuels with a more probable estimate of 0.28, obtained from FABS (2004). The simulation procedure is then done in the following steps: first, the subsidy is simulated via a shift outward of the demand curve in year 2002. Given the short run supply and demand equations and the equilibrium conditions, new equilibrium prices and quantities are solved. Second, the new equilibrium prices are substituted into the expressions for the long run equilibrium capital stocks in the capital demand equations, giving new predictions for the capital stocks. In all, there are now nine simulated values: the quantities and the prices of the intermediate input factors and the capital stocks, and these values are used as starting values in the subsequent period where the procedure is repeated. The short and long run effects are presented in Table 5 and the adjustment paths are depicted in Figure 3.

The results are interpreted in the following way: in the short run, the district heating plants increase their demand for forest fuels by 10 percent as a response to the subsidy. This has a positive effect on the price of forest fuels, which in turn stimulates the forest owners to increase the supply. Since sawtimber and pulpwood are substitutes for forest fuels in the forest owners supply function, the supply of sawtimber and of pulpwood decrease and their respective prices increase. After adjustments have taken place throughout the system, the equilibrium prices are found to increase by almost 4 percent for sawtimber, more than 6 percent for pulpwood, and as much as 31 percent for forest fuels. The equilibrium quantities of sawtimber and pulpwood, on the other hand, decrease by approximately 0.5 percent and 0.3 percent respectively. The equilibrium quantity for forest fuels increases by more than 8 percent, which implies an adjustment

Table 5: Results from simulation.

		Short run		Long run	
Variable	Init. Val.	Change	%	Change	%
y_s	33.5	-0.16	-0.47	-0.09	-0.28
y_p	26.4	-0.08	-0.31	-0.04	-0.16
y_b	15.3	1.25	8.13	0.63	4.11
w_s	378	13.73	3.63	3.97	1.05
w_p	218	13.23	6.06	5.38	2.46
w_b	214	66.75	30.76	32.58	15.25

Note: Initial value from 2002.

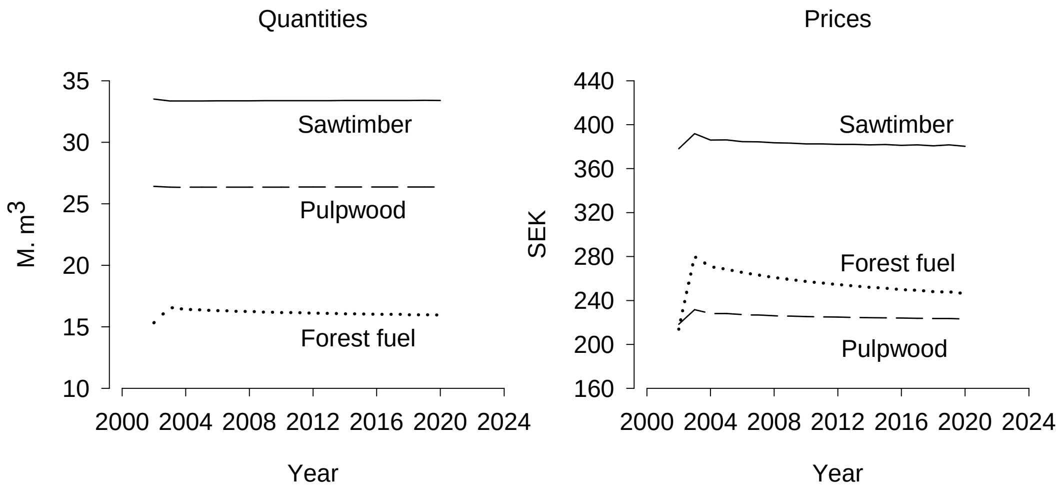

Figure 3: Illustration of a simulated ten percent increase in the demand for forest fuels.

down from the initial 10 percent increase. In the long run, as the capital stocks are adjusted to the new prices, the decreases in the equilibrium quantities of both sawtimber and pulpwood are reduced to approximately -0.3 and -0.15 percent respectively, and the increase in forest fuels is reduced to 4 percent. The initial increase in the prices is reduced to approximately 1 percent for sawtimber, 2.5 percent for pulpwood and 15 percent for forest fuels.

Summing up, the introduction of a subsidy in the energy industry increases the demand for forest fuels and, thereby, the total demand for the forest resources, and has a positive effect on all the prices. There is, however, a negative effect on the quantities of sawtimber and of pulpwood. In addition, the short run responses have the greatest magnitude, whereas in the long run they seem, generally, to reduce to roughly half the size.

We proceed by comparing the value of the equilibrium quantities before the subsidy, to the value of the long run equilibrium quantities after the subsidy, at the new prices. The value of all three types of equilibrium wood quantities increases; for sawtimber by 97 M.SEK, for pulpwood by 132 M.SEK and for forest fuels by 654 M.SEK. From this we see that the forest owners are winners from an introduction of the subsidy. They sell less sawtimber and pulpwood but more forest fuels, and the total value of their sales increases by 883 M.SEK. The sawmill industry and the pulp industry lose from the introduction of a subsidy. They buy less quantities to higher prices. The energy industry is a winner as the introduction of the subsidy makes the industry afford buying more forest fuels.

6 Concluding comments

In this study we have analyzed the short and long term effects on the forest sector, of an increase in the demand for biofuels. To do this we have first developed and estimated a dynamic model of the forest sector, and in a second step the supply and demand elasticities have been calculated for the three central types of wood: sawtimber, pulpwood and forest fuels. Adjustment costs are incorporated in the model, and a partial adjustment approach has been used for modelling the dynamics. This enables calculation of intermediate and long run elasticities in addition to the short run elasticities.

The background to this study is that the use of biofuels in Sweden has been steadily increasing since the early 1970s. Moreover, Sweden has committed to an energy policy increasing the use of renewable resources in the energy system. This indicates that biofuels will have an even greater impact in the future. The increase in demand for biofuels may have effects outside the energy industry, most notably in the forest sector. It is, therefore, important to study how a more ecologically sustainable energy policy will affect the competition for forest resources.

The empirical analysis shows that the partial adjustment model describes the demand side of the model reasonably well since the underlying assumptions are not violated and since the elasticities are all reasonable. The LeChatelier principle is met for all the elasticities except for four of them. The capital adjustment costs are important in determining the path to long term responses. The results indicate that capital adjusts to optimal level in approximately 10 years for the sawmills, in 8 years for the pulp and paper industry. However, capital in the energy industry seems to take more than 40 years to adjust to its optimal level. This is unlikely to be the case and it suggests, instead, that the adjustment function parameter is much underestimated.

One of the energy policy objectives for Sweden is to reduce the emissions of greenhouse gases so that it, by 2010, is at least 4 percent lower than the 1990 levels. To meet this goal a continuous conversion of the energy system will presumably be needed. One way for the government to help such a conversion in the right direction could be to stimulate the use of forest fuels in the energy industry. Therefore the analysis ends with a simple illustration of short and long run effects of a policy shift to increase the energy industry's demand for forest fuels. The simulation results should say something about the tendency in direction rather than in magnitude. The introduction of a subsidy in the energy industry increases the demand for forest fuels and, thereby, the total demand for the forest resources, and has a positive effect on all the equilibrium prices. There is, however, a negative effect on the equilibrium quantities of sawtimber and pulpwood. In addition, the short run responses have the greatest magnitude, whereas in the long run they seem, generally, to reduce to roughly half the size. The results also indicate that the sawmill industry and the pulp industry are losers from such a subsidy, whereas the forest owners and the energy industry are winners.

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