Incorporating Data and Theory in Roundwood Supply and Demand Estimation

Lauri Hetemäki and Jari Kuuluvainen

This paper examines the aggregate pulpwood market in Finland using the econometric approach advocated by Hendry, Neale, and Joba and Spanos, who propose a statistically consistent way to estimate simultaneous-equations models. Private nonindustrial timber supply is estimated along with a three-input demand function (capital, labor, and wood). Results indicate that short-term supply reacts positively to an increase in stumpage price, while the long-term (total) elasticity is negative and small in absolute terms. Capital is a complement while labor is a substitute for roundwood input. Dynamic adjustment process, substitution and cross-price effects, and capital market imperfections implied by the present study differ from those obtained in previous research.

Key words: roundwood markets, simultaneous-equations model, statistical validity.

Since the pioneering study by McKillop, a number of econometric analyses of roundwood and forest product markets have appeared in the U.S. (Adams and Haynes; Newman) and in Scandinavia (Brännlund, Johansson, and Lofgren; Kuuluvainen et al.; Hultkranz and Aronsson). Although these studies have greatly increased our understanding of the basic relationships affecting roundwood markets, recent developments in time-series methods and simultaneous-equations estimation (Engle and Granger; Hendry, Neale, and Srbal 1988, Phillips and Durlauf; Spanos 1990) provide new insights. For example, assumptions made in earlier studies concerning short-term dynamics, substitution and cross-price effects, and effects of capital market imperfections on nonindustrial private wood supply can be examined in a more systematic way.

The purpose of this paper is to provide new evidence on the functioning of the pulpwood market in Finland. The study should also be of general interest for empirical applications of small simultaneous equations systems. We apply recent advances in time-series econometrics and simultaneous-equations estimation as proposed by Hendry, Neale, and Srba (1988) and Spanos (1990) (hereafter the HS approach) to estimate demand for and supply of pulpwood using annual data from 1960 to 1988. Results are compared with an earlier specification of the pulpwood market (Kuuluvainen et al.), which we reestimate using a number of tests not previously employed in roundwood market studies. The new model implies revisions of several hypotheses concerning the pulpwood market.

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Theoretical Model of Pulpwood Market

Nonindustrial private forest (NIPF) owners are the main suppliers of raw material to forest-based industries in Finland (see Kuuluvainen et al. for a description of the institutional framework of the Finnish pulpwood market). Assuming imperfect capital markets (Kuuluvainen), or uncertainty (Koskela), optimal timber supply and consumption must be decided simultaneously. Variables affecting optimal consumption decisions also affect optimal harvest decisions. Using a two-period Fisherian consumption-savings model for optimal harvest decisions under selective credit rationing, the behavioral supply equation becomes (Kuuluvainen and Salo)

$$(1)\quad Q_t^s = Q^s(\underset{+/-}{P_t},\ \underset{-/+}{P_{t+1}},\ \underset{-/+}{R_{t+1}},\ \underset{+}{V_t},\ \underset{-}{I_t},\ \underset{+}{I_{t+1}},\ \underset{-}{\bar{B}_t},\ \underset{+}{\delta})$$

where P_i is pulpwood price net of harvest costs ($i = t, t + 1$), R_{t+1} is market interest rate, V_t is stock of growing merchantable timber, I_i is exogenous nonforestry income ($i = t, t + 1$), $\bar{B}$ is exogenous credit limit faced by an individual forest owner, δ is subjective rate of time preference, and pluses and minuses refer to hypothesized coefficient signs.

Under selective credit rationing, effects of prices and interest rate cannot be determined a priori. The price effect of the credit-rationed forest owner contains both a positive substitution effect and a negative income effect. The sign of the interest rate is undetermined because for credit-rationed suppliers its effect is negative but for nonrationed ones positive. Implications of other types of market imperfections are similar to those of selective credit rationing. The essential point is that, in the presence of market imperfections, forest owners' income also affects supply. When aggregated data are used, it is reasonable to assume that neither credit rationing faced by individual forest owners nor the subjective rate of time preference have a systematic pattern over time. Further, because it is not generally possible to measure these variables with aggregated data, they are not included in the empirical analysis. The allowable drain series is used to approximate the stock of growing timber (see appendix).

Paper industry output can be described using the production function

$$(2) \qquad Y_t = F(K, L, Q)$$

where K is capital input, L is labor input, and Q is the wood raw-material input needed to produce an amount Y_t of final product. It is implicitly assumed that K, L, and Q inputs are weakly separable as a group from the residual inputs (materials and energy). Firms in the pulp and paper industry are assumed to sell final products on competitive export markets at given prices PX_t. Ignoring raw material inventory decisions and uncertainty in short-term production decisions, the profit-maximizing problem of the representative firm can be used to derive the short-term demand function for pulpwood (Brännlund, Johansson, and Lofgren):

$$(3) \qquad Q_t^d = Q^d\,(\underset{+}{PX_t},\ \underset{-}{P_t},\ \underset{+/-}{W_t},\ \underset{+/-}{C_t})$$

where Q_t^d is demand for pulpwood, PX_t is export price of final products, P_t is stumpage price, W_t is unit labor cost, and C_t is price of capital. Effects of wages and capital are uncertain because we cannot deduce a priori whether roundwood is a technical complement or a substitute for these inputs.

Research Results

The modeling strategy is determined by the time-series properties of the data. For example, "error correction" or "cointegration" models have become popular for analyzing nonstationary time series data (Engle and Granger; Hendry and Ericsson). Further, for statistical validity it is important to know whether the series are stationary or not (Phillips; Phillips and Durlauf). Thus we computed the autocorrelation functions and autoregressive processes of our series and tested their normality and stationarity. Logarithmic transformations of the original (annual) series from 1960 to 1988 are used and all price series are deflated (see appendix).

Properties of Time Series

Time-series properties were examined by computing for each series the autocorrelation functions, autoregressive processes (AR), distribution functions, Jarque-Bera normality test (Hendry 1989), Dickey-Fuller test (Fuller), modified Dickey-Fuller test (DF*) (Perron), and Durbin-Watson unit root test (CRDW) (Bhargava, Engle and Granger).

Results (reported in Hetemäki and Kuuluvainen) of the autocorrelation functions showed that user cost (C_t), wages (W_t), exogenous income (I_t), and allowable drain (V_t) levels are not stationary. However, their first differences appear to be stationary, and they can be regarded as $I(1)$ series. All the other series appear to be $I(0)$. Results of regressing each level series on its five own-lags indicated that all the series follow a first-order autoregressive [AR(1)] process.

According to the DF and CRDW test, the Q_t series follows a $I(0)$ process, the P_t series being just below the 5% critical values, while all other series are clearly nonstationary. The DF* test showed that if the one-time changes (1967 devaluation and 1973 oil crisis) are filtered out and a time trend is included, all series except W_t and V_t are $I(0)$. Thus, nonstationarity, apparent in many expanding roundwood markets (Brännlund, Johansson, and Lofgren, and Newman), is not a problem for the Finnish pulpwood market data used here. Therefore, cointegration models are not relevant for modeling pulpwood supply and demand in the present study (Engle and Granger). Tests on W_t and C_t on the one hand, and on V_t and I_t on the other, indicated that although the series themselves are $I(1)$, their linear combinations are stationary (i.e., they are cointegrated).[1] Thus their OLS estimates are asymptotically (super) consistent, but their distributions are nonnormal.

Statistical and Econometric Model

Following Hendry, Neale, and Srba (1988) and Spanos (1990), we draw a distinction between the statistical model (system or reduced form) and the econometric model of the system. The statistical model is defined by the relevant variables suggested by theory, by the variables' status (modeled versus nonmodeled variables), and by the lag polynomials involved. The statistical model summarizes the sample information and ensures the statistical assumptions are valid for the data used. If the reduced form is not statistically valid, there is little point in imposing further restrictions on it, because tests thereof will be against an invalid baseline. Once the reduced form has been found to be statistically adequate, the structural model is derived through imposing zero restrictions implied by theory. Validity of the structural econometric model is judged on the basis of overidentifying restrictions and diagnostic tests.

In the process of model specification, the HS approach emphasizes statistical adequacy rather than the modeler's subjective decisions. For example, the problem of "multiple hypotheses"—too many structural models supporting the data—is tackled in a systematic framework. To make structural models directly comparable, a common statistical model (reduced form) is first estimated and its statistical validity checked. Second, the overidentifying restrictions implied by theoretical hypotheses and their statistical validity are tested. Among the models that survive the first two stages, selection is made on the basis of parameter constancy, parsimony, and the encompassing test (Hendry 1988).

Statistical Model

Supply and demand equations (1) and (3) determine the basic variables to be included in our statistical model, but dynamics are dictated by the data. Even in the case of a "two-period" theoretical pulpwood supply equation, it is not possible to derive a priori the explicit adjustment process. Theory does not specify how quickly agents react to changes in prices and the choice of expectations structure is ad hoc. We make no a priori assumptions about dynamic behavior and consequently do not address the role of expectations explicitly.

Short-term dynamics are taken into account by including lagged variables. Because of the small sample size and large number of variables, only a limited number of lags can be introduced simultaneously. Based on experiments with differing lag structures, a system consisting of (4) and (5) was found (using tests similar to those reported in table 1) to be statistically the most adequate summary of the sample information:

$$(4)\quad P_t = \alpha_0 + \alpha_1 Q_{t-1} + \alpha_2 Q_{t-2} + \alpha_3 P_{t-1} + \alpha_4 PX_t + \alpha_5 R_t + \alpha_6 R_{t-1} + \alpha_7 I_t + \alpha_8 V_t + \alpha_9 W_t + \alpha_{10} C_t + \omega_t$$

$$(5)\quad Q_t = \beta_0 + \beta_1 Q_{t-1} + \beta_2 Q_{t-2} + \beta_3 P_{t-1} + \beta_4 PX_t + \beta_5 R_t + \beta_6 R_{t-1} + \beta_7 I_t + \beta_8 V_t + \beta_9 W_t + \beta_{10} C_t + \upsilon_t$$

where ω_t and υ_t are error terms ($\approx IN(0, \sigma^2)$). Because the reduced form is a statistical summary of sample information, parsimony is not required at this stage and the model is deliberately overparameterized. When estimated with OLS, (4) and (5) passed all tests derived from the classical assumptions of a linear regression model (see table 1). However, because of the small sample size, precise estimation of reduced-form parameters is not possible.

Econometric Model

The structural supply equation was derived by imposing on (4) the zero restrictions implied by (1). The demand equation was derived by imposing on (5) the zero restrictions suggested by (3). However, we were unable to find a statistically valid demand equation when the export price (PX_t) was included explicitly in the structural model.[2] High collinearity of the real export price and real stumpage price indicates that fluctuations in export prices are transmitted to stum-

[1] Although the DF* test indicates the W_t series is not $I(0)$, while C_t is $I(0)$, DF and CRDW tests show that these series are both $I(1)$ and cointegrated. As the structural changes are not filtered out in our estimates, the cointegration result appears reasonable.

[2] When export price was included in the reduced form instead of lagged stumpage price, the structural form did not pass the overidentifying test and the demand equation fitted the data poorly with 2SLS.

Table 1. Estimated OLS Results for Reduced Form Equations (Statistical Model), 1960–1988

$$P_t = -8.14 + \underset{(1.96)}{0.42P_{t-1}} + \underset{(0.50)}{0.09Q_{t-1}} + \underset{(0.77)}{0.14Q_{t-2}} + \underset{(0.33)}{0.25C_t} - \underset{(0.18)}{0.07W_t} - \underset{(0.36)}{0.27I_t} + \underset{(0.95)}{0.01R_t} - \underset{(1.34)}{0.01R_{t-1}} + \underset{(0.28)}{0.66V_t} + \underset{(2.12)}{1.35PX_t}$$
$$(1.02)$$

$$Q_t = -9.12 - \underset{(3.80)}{.82P_{t-1}} + \underset{(1.69)}{.29Q_{t-1}} - \underset{(0.59)}{.12Q_{t-2}} + \underset{(0.59)}{.45C_t} - \underset{(0.88)}{.33W_t} - \underset{(0.06)}{.05I_t} + \underset{(0.33)}{.003R_t} - \underset{(0.445)}{.004R_{t-1}} + \underset{(1.32)}{3.06V_t} + \underset{(0.53)}{.34PX_t}$$
$$(1.14)$$

Model	RSS	R^2	DW	F_{rac}	X^2_n	F	F_c	F_{arch}
P_t	0.40	0.74	1.99	2.00	0.08	4.66	0.20	0.63
df.				3,13	2	10,16	1,15	3,10
Q_t	0.40	0.75	2.07	2.16	1.38	4.74	2.87	0.28
df.				3,13	2	10,16	1,15	3,10

Notes: *df* denotes degrees of freedom. Symbols of test statistics are explained in the appendix; *t*-statistics are in parentheses; P_t is stumpage price, Q_t is pulpwood quantity, C is user cost, W_t is wages, I_t is disposable income, R_t is bank lending rate, V_t is allowable drain, and PX_t is export price.

page prices (Forsman and Heinonen). Because the demand equation is homogeneous of degree zero in product and factor prices, one of the prices can be factored out. We used the production price index in the demand equation as a proxy for the price of "other inputs" (energy and residual materials) and the export price, and consequently as a deflator. Because the production price index is almost identical to the nominal export price series, export price information is implicitly included. However, we are not able to obtain an estimate for the elasticity of demand with respect to the export price.

On the basis of several diagnostic tests (tables 2 and 3) the structural model was derived as

$$(6) \quad Q_t^s = \alpha_0 + \alpha_1 P_t + \alpha_2 P_{t-1} + \alpha_3 I_t + \alpha_4 V_t + \alpha_5 \Delta R_t + \alpha_6 \Delta Q_{t-1} + \epsilon_t \qquad \epsilon_t \simeq IN(0, \sigma^2)$$

$$(7) \quad Q_t^d = \beta_0 + \beta_1 P_t + \beta_2 P_{t-1} + \beta_3 W_t + \beta_4 C_t + \beta_5 Q_{t-1} + \mu_t \qquad \mu_t \simeq IN(0, \sigma^2).$$

Both supply and demand equations include variables that are $I(1)$ series. Because the I_t and V_t series in (6) are cointegrated, as are W_t and C_t in (7), their parameter estimates are asymptotically super consistent, but the distribution of their *t*-values is nonstandard (Fuller; Engle and Granger). Equations (6) and (7) were estimated with OLS, Recursive Least Squares (RLS), 2SLS, and 3SLS. Because 3SLS results did not differ significantly from 2SLS, we report only the latter.

Supply Results

Estimated results for supply equation (6) (referred to as S1A and S1B) are given in table 2. Reestimations of the pulpwood supply equation of Kuuluvainen et al., where

$$(8) \quad Q_t = \phi_0 + \phi_1 P_t + \phi_2 P_{t-1} + \phi_3 SP_t + \phi_4 Q_{t-1} + \phi_5 \Delta I_t + \pi_t$$

are also reported in table 2 (referred to as S2A and S2B). In (8), adaptive pulpwood price expectations are assumed, the cross effect from the sawtimber stumpage price (SP_t) is specified, and disposable income is included as a first difference.[3] Estimates of the Kuuluvainen et al. model were originally computed for the period 1965–1985 using 2SLS, employing a correction for autocorrelation. Here we have reestimated it for the period 1960–1988 without the autocorrelation correction.

Estimated parameters of the $I(0)$ variables in (6) are significant using OLS. The overidentification test ($\chi^2_{OI} \sim$ test) in 2SLS estimates indicated the restrictions imposed on the reduced form are valid. This implies that the structural model parsimoniously encompasses the unrestricted reduced form (Hendry 1988). Parameter estimates are not very sensitive to estimation method, except for the stumpage price variable. All other coefficients are of similar magnitude and *t*-values show that 2SLS does not increase efficiency. OLS produces markedly higher *t*-values of some of the parameters (P_t, P_{t-1}, V_t, ΔR_t) than does 2SLS.

Comparing OLS results of the two alternative modeling approaches, one can see that the new specification (S1A) has a better fit than the old one (S2A). Further, model S1A is a statistically valid representation of the data, while model S2A is not. S2A does not pass the *F*-test (F_{RAC}) for

[3] According to the omitted variable test, the cross effect of the sawtimber stumpage price was not significant and was omitted from the new specification (6) of the supply function.

Table 2. Estimated Results for Supply of Pulpwood, 1960–1988

Independent variable	S1A OLS	S1B 2SLS	S2A OLS	S2B 2SLS
Constant	−7.08	−7.42	3.26	2.00
	(4.16)	(3.76)	(2.73)	(1.85)
Pulpwood price, P_t	0.65	0.81	0.53	0.07
	(4.95)	(1.86)	(2.57)	(0.17)
Lagged pulpwood price, P_{t-1}	−1.01	−1.08	−0.82	−0.61
	(8.68)	(4.99)	(5.20)	(2.70)
Disp. income, I_t	−0.59	−0.68		
	(2.85)	(2.15)		
Δ Disp. income, ΔI_t			−0.14	−0.40
			(−0.19)	(0.49)
Allowable drain, V_t	4.41	4.66		
	(5.24)	(4.30)		
Lagged endogenous variable, Q_{t-1}			0.44	0.49
			(3.34)	(3.28)
Δ Lagged endog. variable, ΔQ_{t-1}	0.21	0.22		
	(2.48)	(2.39)		
Δ Interest rate, ΔR_t	−0.01	−0.02		
	(2.37)	(1.63)		
Sawtimber price, SP_t			−0.12	0.20
			(0.46)	(0.57)

Model	*RSS*	R^2	DW	F_{rac}	χ^2_n	F	F_c	F_{arch}	F_f
S1A	0.21	0.85	1.94	0.33	1.20	22.3	1.33	0.23	0.66
df.				3,17	2	6,20	1,19	3,14	3,17
S2A	0.54	0.66	1.29	4.12	0.33	8.49	7.54	0.17	0.96
df.				3,19	2	5,22	1,20	3,16	3,19

Model	*RSS*	χ^2_i	DW	χ^2_{rac}	χ^2_n	$\chi^2_{a=0}$	χ^2_{oi}	F_{arch}	χ^2_f
S1B	0.22	0.44	1.80	0.11	0.854	2188	8.47	0.05	1.19
df.		(2)/2		(3)/3	2	(7)/7	5	3,14	(3)/3
S2B	0.66	5.29	1.60	4.09	0.49	968	32.46	0.45	1.84
df.		(2)/2		(3)/3	2	(6)/6	4	3,16	(3)/3

Notes: *df.* denotes degrees of freedom. Symbols of test statistics are explained in appendix;[2] *t*-statistics are in parentheses. Because of the different estimation methods, A and B models have different test statistics.

serially correlated errors, as also indicated by the low DW statistics. Also, S2A does not pass the test for correct functional form specification (F_c-test for linearity) and is overidentified (χ^2_{OI}-test). Because S2A is not a statistically valid representation of the DGP, there is no need to compute the encompassing test.

Likely superiority of model S1A becomes even more obvious when one looks at figures 1 and 2. Figure 1 gives the actual and fitted values. One can see that S2A systematically underpredicts the observed quantity traded during the 1980s (even after correction for autocorrelation, as can be seen from Kuuluvainen et al.) and is, without dummy variables, unable to produce the turning points of the recession after the mid 1970s. It is clear from figure 2, which shows RLS estimates for the stumpage price coefficient P_t, that the coefficient in S1A is more stable than in S2A. In figure 3, recursive residuals of S1A are shown with the (±2) standard error lines. Each recursive residual is the error in a one-step-ahead forecast and is compared with its standard deviation under the null hypothesis in order to test whether the dependent variable at time t might have come from the model fitted to all the data up to t. The lower portion of the figure shows the probability values of those sample points such that the hypothesis of parameter constancy would be rejected at the 5, 10, or 15% level. The residuals fall within the standard error bands, indicating parameter stability. The same plot for S2A, not shown here, revealed instability.

In S1A, short-term supply reacts positively to an increase in stumpage price: elasticities are 0.65 with OLS and 0.81 with 2SLS. Long-term or total supply elasticity is negative and rather small in absolute terms: −0.36 with OLS and −0.27 with 2SLS. The *F*-test for omitted variables

Table 3. Estimated Results for Demand for Pulpwood, 1960–1988

Independent variable	D1A OLS	D1B 2SLS	D2A OLS	D2B 2SLS
Constant	3.83	4.54	−2.22	−6.96
	(5.34)	(4.84)	(0.69)	(1.48)
Pulpwood price, P_t	0.43	0.14	0.39	−0.35
	(3.21)	(0.49)	(1.87)	(0.77)
Export price, PX_t			0.36	1.29
			(0.80)	(1.76)
Lagged pulpwood price, P_{t-1}	−0.92	−0.79		
	(6.13)	(3.83)		
Lagged endogenous variable, Q_{t-1}	0.35	0.36	0.09	0.30
	(3.25)	(2.83)	(0.54)	(1.28)
User cost, C_t	−0.34	−0.24		
	(0.98)	(0.59)		
Wage, W_t	0.38	0.37		
	(2.48)	(2.10)		
D75/76			−0.69	−0.48
			(4.47)	(2.15)
D77/78			−0.59	−0.40
			(3.71)	(1.80)

Model	*RSS*	R^2	DW	F_{rac}	χ^2_n	F	F_c	F_{arch}	F_f
D1A	0.35	0.78	1.64	1.15	1.71	15.70	3.18	0.15	0.67
df.				3,19	2	5,22	1,21	3,16	3,19
D2A	0.56	0.65	2.09	0.70	0.30	8.06	7.06	4.00	0.06
df.				3,19	2	5,22	1,21	3,16	3,19

Model	*RSS*	χ^2_i	DW	χ^2_{rac}	χ^2_n	$\chi^2_{a=0}$	χ^2_{oi}	F_{arch}	χ^2_f
D1B	0.42	1.99	1.80	0.95	2.21	1408	8.47	0.33	0.65
df.		(3)/3		(3)/3	2	(6)/6	5	3,15	(3)/3
D2B	0.87	2.77	2.52	3.35	0.69	734	32.46	1.91	0.15
df.		(2)/2		(3)/3	2	(6)/6	4	3,16	(3)/3

Notes: *df.* denotes degrees of freedom. Symbols of test statistics are explained in apppendix;[2] *t*-statistics are in parentheses. Because of the different estimation methods, A and B models have different test statistics.

(Hendry 1989) suggests the long-term effects of disposable income and annual allowable drain must be included. Elasticity of supply with respect to disposable income is −0.58, which is larger than the elasticities obtained from micro data (Kuuluvainen and Salo). The large elasticity for the allowable cut should not be interpreted as elasticity of supply with respect to changes in growing timber stock because the variable measures the aggregated annual incre-

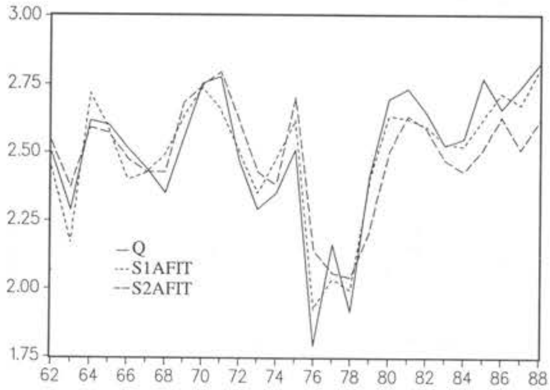

Figure 1. Actual and fitted values of S1A and S2A

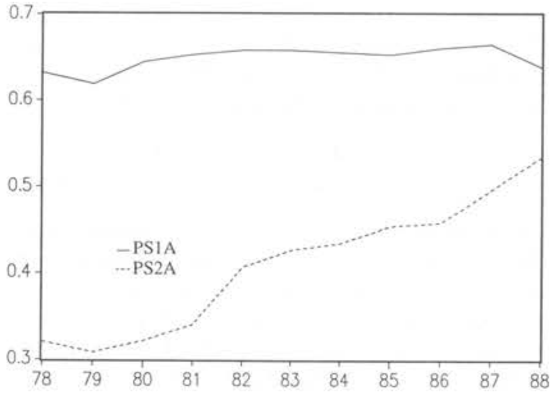

Figure 2. Recursive estimates of stumpage price

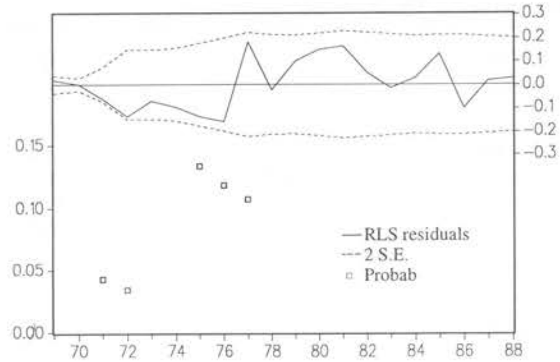

Figure 3. Recursive residuals of S1A

ment. Coefficients of first differences of the interest rate and lagged endogenous variable capture short-term structural shocks. However, detailed interpretation of the impact effects is ambiguous. For example, in the present study, the interest rate impact may be related to inflationary expectations, to changes in monetary policy, or to some other factor. Lagged dependent variable and interest rate do not seem to have long-term effects on timber supply because their levels, present or lagged, were rejected by the F-test when the difference terms were included.

Though elasticities of stumpage prices in S1A and S2A are not markedly different from one another, the dynamics implied by the two specifications are completely different. This is an important result as far as short-term forecasting is concerned. Further, according to S1A, disposable income seems to have a long-term effect on pulpwood supply.

Demand Results

Estimated results of demand equation (7) are compared to those obtained from reestimating Kuuluvainen et al.'s demand equation

$$(9)\quad Q_t = \delta_0 + \delta_1 P_t + \delta_2 PX_t + \delta_3 Q_{t-1} + \delta_4 D75/76 + \delta_5 D78/79 + \eta_t$$

where $D75/76$ and $D78/79$ are dummy variables taking account of structural changes connected with export market developments after the energy crisis. OLS and 2SLS estimates of (7) and (9) are shown in table 3; they are referred to as D1A, B and D2A, B, respectively.

Table 3 shows the new specification (D1A, B) has a better fit than the earlier one (D2A, B). D1A passes all diagnostic tests, while D2A fails the test for correct functional form (F_c-test for linearity); further, low t-statistics indicate problems. In fact, the F_{arch}-test shows that heteroskedasticity is a problem for D2A; and when heteroskedastic-consistent standard errors (not reported here) are used to compute t-values, only the $D77/78$ dummy variable had a t-value above 2. Although diagnostic tests for 2SLS estimates of model 2 (i.e., D2B) indicate no significant specification problem, these test statistics are poorer than for D1B. The residual sum of squares (RSS) indicates high model variance, and D2B clearly fails the overidentification test.

Figure 4 shows actual and fitted values of OLS estimates. The plots indicate that D1A tracks variations in the dependent variable better than does D2A. However, D1A fails to some degree to take account of structural changes in 1976–1978 following the energy crisis. Because of the dummy variables, D2A is better in tracking actual behavior during 1978–80. Plots of recursive residuals indicated that for 1978–1988, D1A is somewhat more stable than D2A. A plot illustrating the RLS estimates of the stumpage price coefficients indicated that estimates are stable in both models.

The short-run elasticity of demand (D1A) with respect to the stumpage price is positive (0.43 in OLS and 0.14 and insignificant in 2SLS), while the long-run (total) elasticity is negative (−0.76 in OLS and −1.03 in 2SLS) as predicted by theory. The positive short-run parameter is not inconsistent with theory, because the theoretical model does not imply any specific short-term adjustment. Positive elasticity in the short run may result from correlation between the present period's stumpage price and the ex-

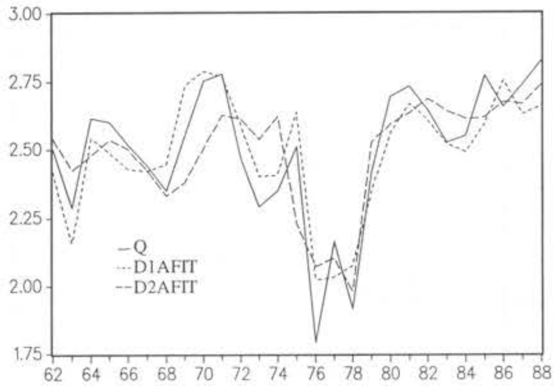

Figure 4. Actual and fitted values of D1A and D2A

port price changes, or to price expectations concerning the stumpage price and export price. OLS estimates of the Q_{i-1} parameter (0.36) indicates rather slow adjustment. The coefficient of the user cost is negative and that of the wage rate is positive, indicating that capital is a technical complement while labor is a technical substitute for roundwood input.[4]

Conclusions

We examined a small dynamic simultaneous-equations model of the Finnish pulpwood market employing recent developments in time-series econometrics and systems estimation. Using the Hendry-Spanos approach, we were able to find a statistically valid econometric specification derived from the theoretical model and which is congruent with the underlying data generation process.

Our model results indicate short- and long-run stumpage price elasticities of supply (0.81 and −0.27) are similar to those in Kuuluvainen et al. Using difference terms, structural shocks related to the severe recession in the mid 1970s can be explained reasonably well without dummy variables. Further, and as indicated by theory, measures of total merchantable timber volume and long-term effect of disposable income should be included in the supply specification. Contrary to earlier findings, stumpage price seems to have both a long-term and short-term effect on pulpwood demand. The long-term effect is negative as predicted by the theory, while the short-term effect is positive and possibly related to export price or stumpage price expectations.

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[4] We computed the encompassing test (see Hendry 1988) for OLS supply and demand equations (models S1A and D1A). Results showed the demand equation does not contain information included in the supply equation but that the supply equation includes specific features not incorporated in the demand equation. Results also indicated the supply equation encompasses the reduced form. Thus, if one is interested only in short-term forecasting, the structural "supply" specification should be used. This result is interesting in that it is commonly recommended that if predictions only are desired, the estimated reduced form should be used (see Judge et al., p. 573).

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Appendix 1

Data and Variables

Stumpage quantity (Q_t) is the total quantity of spruce, pine, and nonconiferous pulpwood from nonindustrial forests traded in felling seasons (mill cu m). Roundwood purchased in a particular felling season is mainly used in industry during the following calendar year. *Source: Archives of the Department of Mathematics, Finnish Forest Research Institute (FFRI).*

Stumpage price (P_t) is the (quantity) weighted average of stumpage prices (FIM/cu m) for different types of wood in cutting seasons. Stumpage prices are prices agreed upon in sales on the stump. *Source: Yearbook of Forest Statistics, FFRI.*

Export price (PX_t) is the price index (1949 = 100) of exports (fob) for the manufacture of paper and paperboard (SITC 64). *Source: ASTIKA, Central Statistical Office of Finland (CSOF).*

User cost of capital (C_t) was calculated using the formula, $C_t = q_t(r_t + d - g_t)/p_t$, where C_t is user cost, r_t is average bank lending rate, q_t is implicit price index of investment, d is depreciation rate, g_t is capital gains (expected change in prices of capital goods), and p_t is production price index. The constant rate of economic depreciation was obtained using the procedure presented in Kuh and Schmalense. *Sources*: The series for gross fixed capital formation in current and 1985 prices (used to construct the implicit price index of investment) were taken from *National Accounts*, and the production price index and wholesale price index from *Statistical Yearbook of Finland*, both published by the *CSOF*.

Wages (W_t) are defined as total wages plus social security charges divided by hours worked, normalized to 1985 = 1. *Source: National Accounts, CSOF.*

Average bank lending rate (R_t). *Source: Bank of Finland, Monthly Bulletin.*

Disposable income (I_t) is aggregate household disposable income (FIM million). *Source: Bank of Finland Quarterly Model of the Finnish Economy.*

Allowable drain (V). Because the total wood volume is not available on an annual basis, we use the allowable drain (growth adjusted for age structure) as a proxy for this variable. Allowable drain has been estimated using the latest results of the National Forest Inventory and it is assumed that the present level of silvicultural and forest improvement work will be maintained and that intensive utilization of forest resources will be extended to cover all parts of the country. *Source: Yearbook of Forest Statistics, FFRI.*

Appendix 2

List of symbols used for tests

The test symbols used in the tables are explained below. For a detailed description of the tests, see, e.g., Hendry (1989) and Hendry and Ericsson (1991). Residual sum of squares is *RSS*; R^2 is coefficient of multiple determination; DW is Durbin-Watson autocorrelation statistic; F is F -test for whether all parameters, except the constant, are significant; DF is Dickey-Fuller unit root test; DF* is modified Dickey-Fuller test (Perron 1989); CRDW is Cointegrated Durbin-Watson unit root test; F_{rac} is F -test for autocorrelation with lagged dependent variables; F_c is F (RESET) - test for correct functional specification; F_{arch} is Auto Regressive Conditional Heteroskedasticity -test; F_f is Chow test for parameter constancy for N forecasts; χ^2_n is Jarque-Bera normality test; χ^2_i is test for the validity of the instruments used in 2SLS estimation; $\chi^2_{a=0}$ is test for whether all the parameters, except the constant, are significant in 2SLS; χ^2_{rac} is test for autocorrelation with lagged dependent variables in 2SLS; χ^2_f is index of numerical parameter constancy for N forecasts; χ^2_{oi} is overidentification test for the validity of restrictions imposed on the reduced form.