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Joint production and substitution in timber supply: a panel data analysis

Torjus F. Bolkesjø[a], Joseph Buongiorno[b,*] and Birger Solberg[a]

[a]*Department of Ecology and Natural Resource Management, Norwegian University of Life Sciences, Høysskoleveien 14, NO-1432 Ås, Norway*
[b]*Department of Forest Ecology and Management, University of Wisconsin - Madison, 1630 Linden Drive, Madison, WI 53706, USA*

Supply equations for sawlog and pulpwood were developed with a panel of data from 102 Norwegian municipalities, observed from 1980 to 2000. Static and dynamic models were estimated by cross-section, time-series and panel data methods. A static model estimated by first differencing gave the best overall results in terms of theoretical expectations, pattern of residuals, prediction accuracy and parsimony. The results showed that sawlog supply responded positively to its own price (elasticity $e = 0.91 \pm 0.07$) but negatively to the pulpwood price ($e = -0.22 \pm 0.06$). The pulpwood supply responded positively to the price of both pulpwood ($e = 0.53 \pm 0.06$) and sawlogs ($e = 0.20 \pm 0.07$). Sawlog and pulpwood supply had a common elasticity of 2.04 (±0.25) with respect to the growing stock, and of 0.30 (±0.21) with respect to the interest rate. The supply elasticity of substitution of sawlog for pulpwood with respect to their relative price was 0.74 ± 0.04. Policies to raise the annual harvest, which is currently well below the annual growth, should focus on stimulating sawnwood production (thus increasing sawlog prices), because this would increase supply of both pulpwood and sawlogs. Instead, policies to stimulate pulpwood demand (thus increasing pulpwood prices), would give more pulpwood, but less sawlogs.

I. Introduction

Wood is the main cost component in most forest industries, and supply of timber is thus crucial to their economic performance. As a result, studies of timber supply have long been a backbone of forest economics (Duerr, 1962; Johansson and Löfgren, 1985; Nautiyal, 1996).

Knowledge of timber supply is also essential for policy making. For example, in Norway the government recently adopted higher taxes that would necessarily decrease the after-tax price for timber producers (Norwegian Ministry of Finance, 2005). For owners with high incomes from other activities than forestry, after-tax timber prices could decrease by 30%. To what extent this would affect the quantity supplied, and as a result the wood-dependent industries, depends in part on the price elasticity of supply. Quite paradoxically, the government is concurrently discussing new strategies to increase the harvest level, which is well below annual increment. Development of efficient policies in this setting requires knowledge of the determinants of timber supply.

Past empirical timber supply studies fall in two main categories: micro-level analysis with cross-section or

*Corresponding author. E-mail: jbuongio@wisc.edu

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panel data on nonindustrial private forest (NIPF) owners (Binkley, 1981; Dennis, 1989; Carlén, 1990; Hyberg and Holthausen, 1989; Kuuluvainen and Salo, 1991), or macro-analysis, with annual time-series for a large region or a country (Lin, 1979; Brännlund *et al.*, 1985; Newman, 1987; Toppinen and Kuuluvainen, 1997; Mutanen and Toppinen, 2005).

Much knowledge has been obtained through these two venues, but there are still difficulties. Forest owner data are typically censored because private owners do not harvest every year, and econometric estimators for censored data are sensitive to specification errors (Maddala, 1983, p. 178; Greene, 1997, p. 971). Furthermore, even if good timber supply models for individual forest owners were obtainable, a difficulty would still remain in aggregating this individual supply into a regional or national supply.

With aggregate time-series data on the other hand, prices are usually endogenous, correlated with the error due to the simultaneous determination of price and quantity. Instrumental variables may help obtain consistent estimates, but good instrumental variables are typically hard to get. In addition, time-series data of annual timber harvest are usually short, so that the number of degrees of freedom is low, decreasing estimation efficiency. Last, annual time-series data do not vary much, and the variables are often collinear, which increases the SEs (Hsiao, 1986).

The objective of this study was to measure elasticities of supply with a combination of cross-section and time-series data for broad geographic areas rather than individual owners. There are few such panel data sets with repeated observations of timber harvest over many years and locations. Observations in different countries and over time have been used, but with difficulty due to the large differences between countries and the inaccuracy of international data, especially regarding prices (Tomberlin, 1999; Turner and Buongiorno, 2005).

Here, we used a panel data set of 102 Norwegian municipalities over 21 years to study the supply of sawlogs and pulpwood. There was advantage in using data from one single country, since many variables that might influence supply were being held constant, and the definitions of the variables were unlikely to vary excessively. Furthermore, since the observation units were regions (municipalities), not single forest owners, the dependent variable was never truncated.

In addition, the price faced by producers in each municipality could be assumed to be exogenous. Prices are largely determined by the aggregate demand and supply in Nordic markets. Supply and demand shocks in a municipality should have little impact on this large market, and thus on the price, which could thus be assumed independent of the error term.

Hence, the data allowed for the use of the simplest linear panel data estimators with exogenous variables. Within this class several model formulations and estimation methods were still possible. The objective of this article was to apply these methods to determine the most likely model of timber supply, and the corresponding elasticities.

II. Methods

Theoretical model

Almost 80% of forestland in Norway consists of small NIPFs. Therefore, the supply of each municipality is to a large extent the aggregate supply of private forestland owners. In addition, most of the other forestland owners, including municipalities, counties, the government and industry, have efficient timber production as one of their objectives. Hence, the timber supply model used here is based on the theory of the firm in a competitive environment. The model focuses on the short-term supply (i.e. from a given stock of timber). Assuming that forest owners maximize yearly profits, conditional on the current level of growing stock, their optimization problem is:

$$\max_{q_s, q_m} Z = (R(q_s, q_m, p_s, p_m) - C(v, r, p_s, p_m)) \quad (1)$$

subject to:

$$g(q_s, q_m, v) = 0 \quad (2)$$

where Z is the short-term profit, R is the value of the harvest, consisting of sawlogs in quantity q_s and price p_s and of pulpwood in quantity q_m and price p_m. C is the cost of production, which consists largely of the cost of holding the growing stock, v, which depends on the interest rate, r, and on the sawlog and pulpwood prices. The growing stock can be used to obtain various combinations of sawlog and pulpwood, according to the implicit transformation frontier (Equation 2).

Solving this optimization problem, and assuming a Cobb–Douglas functional form leads to the short-term supply functions for sawlog and pulpwood:

$$q_s = \alpha_s p_s^{\beta_s^s} p_m^{\beta_s^m} v^{\gamma_s} e^{\delta_s r} \quad (3)$$

$$q_m = \alpha_m p_m^{\beta_m^s} p_m^{\beta_m^m} v^{\gamma_m} e^{\delta_m r} \quad (4)$$

where e is the base of natural logarithms. Similar equations have been used previously to model timber supply (Adams *et al.*, 1982; Brännlund *et al.*, 1985; Daniels and Hyde, 1986; Kuuluvainen, 1986), but the cross-price effects between sawlogs and pulpwood have not been often examined.

In Equations 3 and 4, we expected the own-price elasticities, β_s^s and β_m^m to be positive. The cross-price elasticities β_s^m and β_m^s could be positive or negative, depending on whether sawlogs and pulpwood are complements or substitutes in production.

Only the largest trees can be sold as sawlogs. Pulpwood, instead, can come from small as well as large trees. Thus, we expected that a rise in the price of pulpwood, which would increase the supply of pulpwood, would decrease the supply of sawlogs, because at least part of the trees of sawlog size would be cut in smaller pieces to make pulpwood. On the other hand, a rise in the price of sawlogs would also raise the supply of pulpwood, because trees that were cut into sawlogs did also produce pulpwood from the residues: smaller parts of the main stem, and branches.

The elasticity with respect to growing stock, γ, was expected to be positive, as harvests should be higher with higher level of growing stock, other things being equal. Last, the elasticity of supply with respect to the interest rate, δ, should also be positive, reflecting a tendency to reduce the cost of holding growing stock as the interest rate increases.

We also considered a dynamic version of Equations 3 and 4. Assuming that producers adjust their harvest only partially to changes in prices, stock or interest rate, or alternatively that their harvest depends on previous formed expectations of prices, leads to a model with lagged harvest as a dependent variable. For example, adaptive expectations suggest that the harvest is updated each year on the basis of the discrepancy between the last actual explanatory variable, x_{-1}, and its expected level x_{-1}^*. Specifically, assume that (Johnston, 1984, pp. 348–9):

$$\frac{x^*}{x_{-1}^*} = \left(\frac{x}{x_{-1}^*}\right)^{\lambda} \tag{5}$$

So that expectations adjust each year by a proportion, $0<\lambda<1$, of the ratio between the expectation formed previously and the current level of the explanatory variable. Then, applying Equation 5 to each explanatory variable and substituting in Equations 3 or 4 leads to the following dynamic supply equation for sawlogs or pulpwood:

$$q = \alpha^{\lambda} p_s^{\lambda\beta^s} p_m^{\lambda\beta^m} v^{\lambda\gamma} e^{\lambda\delta r} q_{-1}^{1-\lambda} \tag{6}$$

where the parameters $\lambda\beta^s$, $\lambda\beta^m$, $\lambda\beta^s$, $\lambda\gamma$ and $\lambda\delta$ are the short-run elasticities of supply with respect to sawlog price, pulpwood price, forest stock and interest rate. This specification is similar to the two-period consumption-saving models assuming utility maximization (Kuuluvainen, 1986), except for the exclusion of owner characteristics, which do not apply with the data used here.

Data

The data were for 102 municipalities in eastern Norway, for each year from 1980 to 2000, leading to a total of 2142 observations. Harvest levels and timber prices were obtained from Statistics Norway (2001). The prices were for timber delivered at roadside. We expressed them in 1998 Norwegian kroner (NOK), using the consumer-price index as a deflator (available at: http://www.ssb.no/kpi). The real interest rate data came from Statistics Norway (2004). The interest rate was assumed to be the same in all municipalities.

Standing timber stock data came from a survey of the forest administration in each county (the 102 municipalities belong to nine different counties) (Kulblik, 2004). The survey asked for the level of timber stock and gross growth in each municipality at the time of the last inventory. When there had been no inventory, the survey asked for the administration's estimate of standing stock and gross growth in 2000. We then estimated the stock level in each year from 1980 to 2000 by taking the stock the previous year, adding the gross growth, and subtracting the removals.

Figure 1 shows the evolution of the total harvest and of the growing stock during the study period. The sawlog harvest declined slightly from 1980 to 2000. The pulpwood harvest increased rapidly in the 1980s.

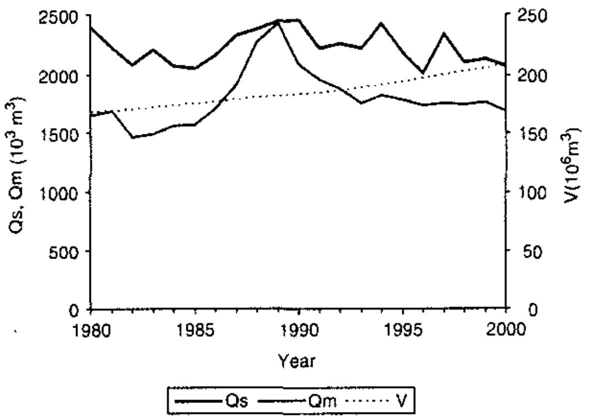

Fig. 1. Total harvest levels of sawlog, q_s, and pulpwood, q_m, and level of growing stock, v, in the 102 municipalities

Table 1. Summary statistics for 2142 observations for 102 municipalities, from 1980 to 2000

	Mean	SD	Minimum	Maximum
Sawlog harvest, q_s (m^3)	25 233	25 276	308	143 918
Pulpwood harvest, q_m (m^3)	20 209	17 683	244	109 593
Sawlog price, p_s (NOK/m^3)	471.9	60.7	322.8	622.1
Pulpwood price, p_m (NOK/m^3)	315.0	59.4	147.7	442.6
Standing stock, v (1000 m^3)	2101	1868	167	10 000
Interest rate, r ($year^{-1}$)	0.068	0.031	0.004	0.12

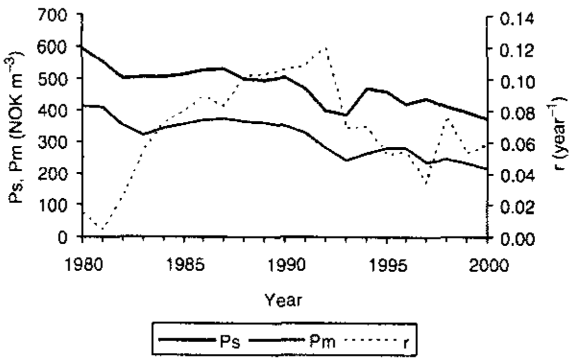

Fig. 2. Average sawnwood price, p_s, pulpwood price, p_m, in the 102 municipalities, and national interest rate, r

Table 2. Variance of the logarithm of variables between municipalities and between years

	Sum of squares	
	Between municipalities	Between years
Sawlog harvest, q_s (m^3)	2077	12
Pulpwood harvest, q_m (m^3)	1725	36
Sawlog price, p_s (NOK/m^3)	1	34
Pulpwood price, p_m (NOK/m^3)	2	79
Standing stock, v (1000 m^3)	1753	9
Interest rate, r ($year^{-1}$)	0	2
Degrees of freedom	101	20

It reached almost the level of the sawlog harvest by 1989. The pulpwood harvest then declined so that it was only 6% higher in 2000 than in 1980. The total growing stock increased steadily throughout the period, at an average rate of 1% per year.

The real prices of sawlog and pulpwood both declined during the study period (Fig. 2), at an average rate of 1.8% (±0.2) per year for sawlog and 2.9% (±0.3) per year for pulpwood. The real interest rate increased from 2% per year to 12% between 1980 and 1993. It then declined and was at 6% per year in 2000.

The summary statistics (Table 1) show that there was much variation in the variables across all observations. Harvested quantities and standing stock varied much more between the municipalities than over time (Table 2). Instead, most of the price variation was due to price changes over time rather than to differences between municipalities.

The strongest partial correlations, over the 2142 observations (Table 3) were between the sawlog and pulpwood harvest, q_m and q_s; between the sawlog or pulpwood harvest and the growing stock, v and between the sawlog and pulpwood prices, p_s and p_m. The partial correlations between the annual changes of these same variables were much weaker (Table 4).

Econometric estimation

The empirical equations were logarithmic forms of Equations 3, 4 and 6, after addition of a stochastic term. Thus, the empirical static model was:

$$\ln q_{it} = \ln\alpha + \beta^{s}\ln p_{it}^{s} + \beta^{m}\ln p_{it}^{m} + \gamma\ln v_{it} + \delta r_{it} + \varepsilon_{it} \tag{7}$$

where the subscript i refers to a municipality and t to a year, and ε is the residual error. The empirical dynamic model was:

$$\begin{aligned}\ln q_{it} = {}& \lambda\ln\alpha + \lambda\beta^{s}\ln p_{it}^{s} + \lambda\beta^{m}\ln p_{it}^{m} + \lambda\gamma\ln v_{it} \\ & + \lambda\delta r_{it} + (1-\lambda)\ln q_{t-1} + \varepsilon_{it}\end{aligned} \tag{8}$$

Equations 7 and 8 were estimated separately for sawlog and for pulpwood. We used the following estimation methods (Wooldridge, 2000, pp. 408–59):

1. The pooled ordinary least squares (OLS) method minimized the sum of squares of ε_{it} in Equations 7 and 8. It thus assumed that the explanatory variables accounted for all systematic variation between municipalities and over time, and that the residual ε_i was normally distributed with mean zero and constant variance.
2. The fixed-effects method assumed that the residual error could be decomposed as follows:

$$\varepsilon_{it} = \mu_i + u_{it} \tag{9}$$

Table 3. Partial correlation of the logarithm of variables over the 2142 observations

	$\ln q_m$	$\ln p_s$	$\ln p_m$	$\ln v$	r
Sawlog harvest, $\ln q_s$ (m^3)	0.95	0.13	0.08	0.87	0.001
Pulpwood harvest, $\ln q_m$ (m^3)		0.09	0.09	0.86	0.08
Sawlog price, $\ln p_s$ (NOK/m^3)			0.88	−0.03	−0.20
Pulpwood price, $\ln p_m$ (NOK/m^3)				−0.05	0.01
Standing stock, $\ln v$ (1000 m^3)					0.01
Interest rate, r ($year^{-1}$)					

Table 4. Partial correlation of the annual change in the logarithm of variables over the 2142 observations

	$\Delta \ln q_m$	$\Delta \ln p_s$	$\Delta \ln p_m$	$\Delta \ln v$	Δr
Sawlog harvest, $\Delta \ln q_s$ (m^3)	0.67	0.26	0.02	0.21	−0.05
Pulpwood harvest, $\Delta \ln q_m$ (m^3)		0.15	0.24	0.16	0.08
Sawlog price, $\Delta \ln p_s$ (NOK/m^3)			0.43	0.05	−0.15
Pulpwood price, $\Delta \ln p_m$ (NOK/m^3)				0.01	0.24
Standing stock, $\Delta \ln v$ (1000 m^3)					−0.08
Interest rate, Δr ($year^{-1}$)					

where μ_i was a municipality-specific constant term. The purpose of this constant term was to control for unobserved factors affecting harvest that might vary between municipalities while remaining constant over time. The residual u_{it} was then assumed to have the usual properties.

(3) The random-effects method assumed that μ_i was a random variable, uncorrelated with the explanatory variables. Under this assumption, estimating Equations 7 and 8 by random effect would be more efficient than fixed effects (Wooldridge, 2000, p. 449). We tested this assumption with Hausman's (1978) method.

(4) The first-differencing method aimed at eliminating the municipality-specific constant in Equation 9 by using the year-to-year change in the variables rather than their level. For example, Equation 7 was replaced by:

$$\begin{aligned}\ln q_{it} - \ln q_{it-1} = {} & \beta^s(\ln p^s_{it} - \ln p^s_{it-1}) \\ & + \beta^m(\ln p^m_{it} - \ln p^m_{it-1}) \\ & + \gamma(\ln v_{it} - \ln v_{it-1}) \\ & + \delta(r_{it} - r_{it-1}) + \varepsilon_{it} - \varepsilon_{it-1} \qquad (10)\end{aligned}$$

In addition, we compared these four panel methods with a pure cross-section and a pure time-series method based on the same data.

(5) The cross-section method estimated the static Equation 7 with data consisting of the yearly average of the observations in each unit. The dynamic Equation 8 could not be estimated in this way.

(6) The time-series method consisted in summing for each year the harvest and stock data over all municipalities, and calculating the corresponding price as the harvest-weighted average of the price in each municipality. The price series were then used to estimate Equations 7 and 8 by OLS.

For each method we computed the serial correlation of the residuals, ρ (except for the pure cross-section method for which serial correlation did not exist), and the within-sample prediction error. For pooled OLS, fixed effects, random effects, and first difference the prediction error was the root mean square error (RMSE) of the regression. For the cross-section and the time-series methods, the prediction error was the RMSE obtained by applying the estimated equations to each municipality and year.

III. Results

Sawlog supply

Table 5 contains the results of estimation of the sawlog supply equations, with the static and dynamic specification, and with different methods. The main results, according to method were as follows:

Cross-section method. The cross-section method (defined for the static model only) gave large, and highly significant, elasticities of supply with respect to the sawlog price and the pulpwood price. The elasticity of supply with respect to the level of

Table 5. Sawlog supply models estimated by different methods

	Panel methods					
	Pooled OLS	Fixed effects	Random effects	First difference	Cross-section	Time series
Static model						
$\ln p_s$	1.58 (0.19)**	0.60 (0.10)**	0.66 (0.10)**	0.89 (0.07)**	11.38 (1.52)**	0.58 (0.31)
$\ln p_m$	−0.26 (0.12)*	0.00 (0.07)	0.07 (0.07)	−0.22 (0.06)**	3.57 (1.09)**	−0.22 (0.24)
$\ln v$	0.97 (0.01)**	0.33 (0.08)**	0.67 (0.06)**	1.83 (0.27)**	0.92 (0.04)**	0.09 (0.20)
r	1.16 (0.37)**	0.47 (0.19)*	0.45 (0.19)*	0.18 (0.23)	n.a.	1.08 (0.48)*
ρ	0.91 (0.01)**	0.62 (0.02)**	0.63 (0.02)**	−0.05 (0.02)*	n.a.	0.39 (0.24)
RMSE	0.47	0.24	0.23	0.19	2.04[a]	0.93[a]
H			46.56**			
Degrees of freedom	2137	2036	2137	2036	98	16
Dynamic model						
$\ln p_s$	0.74 (0.08)**	0.72 (0.08)**	0.76 (0.08)**	0.86 (0.07)**	n.a.	0.64 (0.31)
$\ln p_m$	−0.36 (0.05)**	−0.24 (0.05)**	−0.27 (0.05)**	−0.18 (0.06)**	n.a.	−0.37 (0.26)
$\ln v$	0.12 (0.01)**	0.30 (0.07**	0.33 (0.02)**	1.70 (0.28)**	n.a.	−0.12 (0.48)
r	0.60 (0.16)**	0.60 (0.15)**	0.61 (0.15)**	0.15 (0.24)	n.a.	1.15 (0.50)*
$\ln q_{-1}$	0.89 (0.01)**	0.61 (0.02)**	0.67 (0.02)**	−0.07 (0.02)**	n.a.	0.32 (0.24)
ρ	−0.02 (0.03)	0.07 (0.03)**	0.02 (0.03)	−0.13 (0.09)	n.a.	0.60 (0.57)
RMSE	0.19	0.18	0.22	0.19	n.a.	0.83[a]
H			69.33**			
Degrees of freedom	2034	1933	2034	1933	n.a.	14

Notes: [a]From model applied to all observations across municipalities and over time.
** and * indicate coefficients significantly different from zero at the 1% and 5% levels, respectively.

growing stock was close to one. The RMSE was much larger than with any other method.

Time-series method. The pure time-series method gave RMSEs smaller than the cross-section, but much larger than the panel methods, both for the static and dynamic model. The elasticities had the theoretically expected sign (except for the negative elasticity with respect to growing stock in the dynamic model) but all elasticities except the interest rate elasticities were statistically insignificant at the 5% level.

Panel data methods. The dynamic model led to lower or equal RMSEs than the static model, regardless of the panel data method. First differencing gave a low RMSE for the static and for the dynamic model.

The static model led to high serial correlation of the residuals, regardless of method, except first differencing, which gave a small and barely significant serial correlation. There was practically no serial correlation in the dynamic models estimated with the panel data methods.

The elasticities of sawlog supply with respect to the sawlog price were all positive and similar in magnitude (given the SEs), except for the higher elasticity obtained with the static model estimated by pooled OLS.

The elasticity of sawlog supply with respect to the pulpwood price was negative with the dynamic model, regardless of method, and it was highly significant. The same occurred with the static model estimated by pooled OLS or first difference.

The stock level had a positive and significant effect in all supply equations. But, the elasticity was three to four times larger in the models estimated by first differencing than with the other panel data methods.

The interest rate had a positive effect on the sawlog supply in all specifications. However, the elasticity became insignificant when the static or the dynamic model was estimated by first differencing.

Pulpwood supply

Table 6 contains the results of estimation of the pulpwood supply equations, for the static and dynamic specification, and with different methods. The main results, according to method were as follows:

Cross-section method. As for the sawlog supply equations, the cross-section method gave large, and highly significant, elasticities of supply with respect to the sawlog price and the pulpwood price. The supply was inelastic with respect to the level of growing stock. The RMSE was larger than with any other method.

Table 6. Pulpwood supply models estimated by different methods

	Panel methods					
	Pooled OLS	Fixed effects	Random effects	First difference	Cross-section	Time series
Static model						
$\ln p_s$	0.25 (0.18)	0.26 (0.13)*	0.28 (0.13)*	0.22 (0.07)*	5.58 (1.42)**	−0.09 (0.43)
$\ln p_m$	0.52 (0.12)**	0.34 (0.08)**	0.36 (0.08)**	0.53 (0.06)**	5.88 (1.02)**	0.79 (0.34)*
$\ln v$	0.90 (0.01)**	0.80 (0.10)**	0.89 (0.04)**	2.34 (0.29)**	0.86 (0.03)**	2.29 (0.68)**
r	2.53 (0.40)**	2.57 (0.23)**	2.56 (0.23)**	0.49 (0.24)*	n.a.	1.92 (0.69)*
ρ	0.89 (0.01)**	0.71 (0.02)**	0.72 (0.02)**	0.01 (0.02)	n.a	0.32 (0.24)
RMSE	0.46	0.29	0.28	0.20	1.78[a]	1.35[a]
H			35.50**			
Degrees of freedom	2137	2036	2137	2036	98	16
Dynamic model						
$\ln p_s$	0.36 (0.08)**	0.43 (0.09)**	0.39 (0.09)**	0.29 (0.07)**	n.a.	0.26 (0.36)
$\ln p_m$	0.01 (0.05)	0.09 (0.06)	0.04 (0.06)	0.48 (0.07)**	n.a.	0.33 (0.30)
$\ln v$	0.13 (0.01)**	0.52 (0.07)**	0.30 (0.03)**	2.35 (0.30)**	n.a.	1.33 (0.61)*
r	0.45 (0.17)**	0.85 (0.17)**	0.86 (0.17)**	0.65 (0.25)**	n.a.	1.03 (0.63)
$\ln q_{-1}$	0.87 (0.01)**	0.71 (0.01)**	0.71 (0.01)**	0.05 (0.02)*	n.a.	0.56 (0.16)
ρ	0.11 (0.03)**	0.15 (0.03)**	0.15 (0.03)**	−0.13 (0.09)	n.a.	0.27 (0.34)
RMSE	0.20	0.19	0.21	0.21	n.a.	0.87[a]
H			27.03**			
Degrees of freedom	2034	1933	2034	1933	n.a.	14

Notes: [a]From model applied to all observations across municipalities and over time.
** and * indicate coefficients significantly different from zero at the 1% and 5% levels, respectively.

Time-series method. The pure time-series method gave much larger RMSEs than the panel data methods, both for the static and for the dynamic specification. The elasticities had theoretically plausible signs but several had large SEs.

Panel data methods. With the panel data methods, the dynamic model led to lower RMSEs than the static model, except for first differencing, which gave practically the same RMSE for the static and dynamic version of the model.

All panel data methods applied to the static model led to high serial correlation of the residuals, except first differencing. Serial correlation was also highly significant, but smaller, with the dynamic model estimated by OLS, fixed effects or random effects.

Regardless of method, the static model gave elasticities of pulpwood supply with respect to the pulpwood price that were positive and similar in magnitude given the SEs. However, with the dynamic model, only the first-difference method gave a positive elasticity of pulpwood supply with respect to pulpwood price.

The cross-price elasticity of pulpwood supply with respect to the sawlog price was positive, for the static and dynamic model, regardless of method. It was highly significant in the dynamic model, and similar in magnitude in the static and dynamic model, for all four panel data methods.

The stock level had a positive and significant effect in all supply equations. As in the sawlog supply equation, the elasticity was much larger when first differencing was used instead of another panel data method.

IV. Discussion

An advantage of the approach used in this study is the large number of observations and the high variation in the variables brought about by pooling data across municipalities and over time. The main weakness, data wise, lies in the annual standing stock figures, which were interpolated between inventories – and thus are necessarily imprecise. Substantial correlation existed between the levels of sawlog and pulpwood prices, but the correlation disappeared after first differencing, so that these models gave accurate estimates of the elasticity of supply with respect to each price.

The pure cross-section method did not yield useful estimates of the elasticities of supply with this data set. As it did not use time-related data, it obviously could not be used to estimate a dynamic model. In addition, the effect of the interest rate on supply could not be estimated with this method and data set because the interest rate was the same in all municipalities.

A cross-section approach was feasible with a static model, but the RMSE was so large that the method would be quite useless in this context. Although the price elasticities were highly significant, it is clear that they were seriously biased due to omitted variables correlated with the prices. Instead, the elasticities of supply with respect to growing stock obtained by cross-section analysis were near unity, which seemed plausible.

The pure time-series method could be used with the static and dynamic model, but in both cases it led to large RMSEs, and the elasticities had such large SEs that little could be said confidently about their magnitude.

The four panel data methods were more likely to give useful estimates of the elasticities of supply with this particular data set. However, the methods gave different results, and it was not always easy to choose between them, and between the static and the dynamic formulation of supply.

For pulpwood supply, we could discard the static and the dynamic models estimated by pooled OLS, fixed effects and random effects, on the basis of the significant serial correlation of the residuals, which suggested a specification error, due to omitted variables. The serial correlation was less serious for the dynamic than for the static model, presumably because the lagged dependent variable of the dynamic model was a good proxy for some of the omitted variables, but it was still a source of inconsistency in a dynamic model (Johnston, 1984, p. 363).

Another reason to discard the dynamic pulpwood supply model estimated by pooled OLS, fixed effects or random effects, was that the resulting elasticity of pulpwood supply with respect to its price was very small and not significantly different from zero. It seems implausible that pulpwood supply be independent of the pulpwood price. In contrast, the pulpwood supply model estimated by first difference gave a positive and statistically significant elasticity of supply with respect to pulpwood price, both in the static and dynamic version of the model. As the static and dynamic model estimated by first difference gave very similar results for pulpwood supply, the results of the static version was preferred based on parsimony (Wooldridge, 2000, p. 194).

For sawlog supply we could discard the static model estimated by pooled OLS, fixed effects and random effects, because of the high serial correlation of the residuals, and the higher RMSE than the static model estimated by first difference. The choice was less clear for the dynamic model. All panel methods led to nearly serial correlation-free residuals. The Hausman test did reject random effects in favour of fixed effects, but the two methods gave in fact nearly identical results.

A weakness of the dynamic model is that, regardless of method, the lagged dependent variable was likely to be correlated with the error term, due to time-persistent omitted variables that affected the supply in year t and in year $t-1$. That is, the lagged dependent variable was endogenous, so that the coefficient of the lagged dependent variable reflected in part the effect of omitted variables rather than the effect of past supply only. That there were omitted variables was suggested by the strong serial correlation of the residuals in the static models. Although the effect of these omitted variables was attenuated by the fixed effect and the random effect methods, they were never eliminated. As a result of the endogeneity of the lagged dependent variable the estimates of the dynamic models were likely to be inconsistent (Wooldridge, 2002, p. 299).

In contrast, estimation by first difference eliminated all variation across municipalities, including the variation due to omitted variables. The first difference estimates were therefore more likely to be consistent. Since there was little difference between the static and the dynamic model estimated by first difference, for sawlog and for pulpwood, the results of the simpler static model estimated by first difference seemed preferable. Comparing these models in Tables 5 and 6 we observed that the elasticities of supply with respect to the growing stock and interest rate were similar, given their SEs. The following final models were then obtained simultaneously by seemingly unrelated regression (Zellner, 1962) while constraining the elasticities with respect to growing stock and to interest rate to be the same for sawlog and for pulpwood supply:

$$\begin{aligned}\Delta \ln q^{\mathrm{s}}_{it} &= \underset{(0.07)^{**}}{0.91}\,\Delta \ln p^{\mathrm{s}}_{it} - \underset{(0.06)^{**}}{0.22}\,\Delta \ln p^{\mathrm{m}}_{it} \\ &\quad + \underset{(0.25)^{**}}{2.04}\,\Delta \ln v_{it} + \underset{(0.21)}{0.30}\,\Delta r_t \\ \mathrm{RMSE} &= 0.19, \rho = -0.05 \end{aligned} \tag{11}$$

$$\begin{aligned}\Delta \ln q^{\mathrm{m}}_{it} &= \underset{(0.07)^{**}}{0.20}\,\Delta \ln p^{\mathrm{s}}_{it} + \underset{(0.06)^{**}}{0.53}\,\Delta \ln p^{\mathrm{m}}_{it} \\ &\quad + \underset{(0.25)^{**}}{2.04}\,\Delta \ln v_{it} + \underset{(0.21)}{0.30}\,\Delta r_t \\ \mathrm{RMSE} &= 0.20, \rho = 0.02 \end{aligned} \tag{12}$$

where it can be noted that the constraints had little effect on the price elasticities, the RMSE and the serial correlation. These two equations show clearly the positive effect of the change in sawlog price on the supply of both sawlog and pulpwood, as pulpwood is in part a by-product of sawlog production. Instead, the price of pulpwood has a positive influence on the production of pulpwood, but a negative influence on the production of sawlogs. The latter effect is due to the fact that some of the sawlogs are cut into pulpwood when pulpwood prices are high.

Equations 11 and 12 imply an elasticity of substitution (effect of a price change on the ratio of sawlog to pulpwood supply) of $0.91 - 0.20 = 0.71$ with respect to the sawlog price, and of $-0.22 - 0.53 = -0.75$ with respect to the pulpwood price. The closeness of the two elasticities in absolute value suggested a symmetric expression of the elasticity of substitution:

$$\ln\left(\frac{q_{it}^{s}}{q_{it}^{m}}\right) = \lambda + \sigma \ln\left(\frac{p_{it}^{s}}{p_{it}^{m}}\right) \qquad (13)$$

which, estimated by first difference with the panel data gave the estimate of the elasticity of substitution $\hat{\sigma} = 0.74(\pm 0.04)$.

To test the stability of these results with respect to changes in the data, Equations 11 and 12 were re-estimated without the data for the year 2000, thus removing 102 observations in first difference. The results were:

$$\begin{aligned}\Delta \ln q_{it}^{s} = {} & \underset{(0.06)^{**}}{0.89}\, \Delta \ln p_{it}^{s} - \underset{(0.06)^{**}}{0.22}\, \Delta \ln p_{it}^{m} \\ & + \underset{(0.26)^{**}}{1.90}\, \Delta \ln v_{it} + \underset{(0.21)}{0.31}\, \Delta r_{t} \qquad (14)\end{aligned}$$

$$\begin{aligned}\Delta \ln q_{it}^{m} = {} & \underset{(0.07)^{**}}{0.19}\, \Delta \ln p_{it}^{s} + \underset{(0.06)^{**}}{0.54}\, \Delta \ln p_{it}^{m} \\ & + \underset{(0.26)^{**}}{1.90}\, \Delta \ln v_{it} + \underset{(0.21)}{0.31}\, \Delta r_{t} \qquad (15)\end{aligned}$$

Comparison with Equations 11 and 12 shows that most parameters were stable. The least stable parameter was the elasticity with respect to growing stock, but its variation was well within the confidence interval.

V. Conclusion

The detailed and large data set used in this study allowed a comparison of several methods to estimate timber supply elasticities. It showed that elasticities based on pure cross-section analysis could be very biased and misleading. Pure time-series results, though not necessarily biased, were very inaccurate. Methods that exploited the full panel data set had a better chance of producing useful estimates. But even with panel data, the results varied considerably depending on the method, and on the static or dynamic form of the model.

Part of the difficulty stemmed from the fact that harvest volume and growing stock varied greatly between municipalities, but little over time. Meanwhile, prices and interest rates varied mostly over time rather than between municipalities. Furthermore, while harvest volumes were stationary, prices and growing stock had a strong time trend.

Unfortunately, the strong variation of harvest and growing stock between municipalities was hard to exploit, due to municipality-specific omitted variables that led to biased results in static models, and inconsistent estimates in dynamic models due to the correlation of the lagged dependent variable with the omitted variables.

We concluded therefore that the best estimation method should use the year-to-year changes of the variables within each municipality. This first-differencing procedure effectively eliminated the municipality-specific omitted variables. Regrettably, it also withdrew a large source of information by eliminating the cross-sectional variability in the variables of interest. Still, there were enough observations to obtain useful elasticities of timber supply. But, with a static model based on year-to-year changes only, the elasticities must be short-term, and as such they may underestimate the full long-run impact of changes in prices and growing stock.

The results have clear relevance for the tax-policy debate mentioned in the introduction. Given the price elasticities of supply in Equations 11 and 12, if the tax-reform decreased after-tax prices of sawlog and pulpwood by, say, 10%, the current annual harvest level of 4.3 million m^3 in the municipalities considered would, other things being equal, decrease by approximately 7%, or 167 000 m^3 per year less sawlogs and 136 000 m^3 per year less pulpwood. This would affect not only forest owner incomes, but also competitiveness, production levels and profit margins in forest industries.

The cross-price effects that have been obtained are of high relevance to the current governmental initiative to increase harvest levels. According to the results in Equations 11 and 12, decreasing pulpwood prices would increase sawlog supply, while decreasing sawlog prices would decrease supply of pulpwood. This asymmetry implies that policies to increase the annual harvest, which is currently well below the annual growth, should focus on stimulating sawnwood production (thus increasing sawlog prices), since this would increase supply of both pulpwood and sawlogs. Instead, policies to stimulate pulpwood demand (thus increasing pulpwood prices), would according to the present results give more pulpwood, but less sawlogs.

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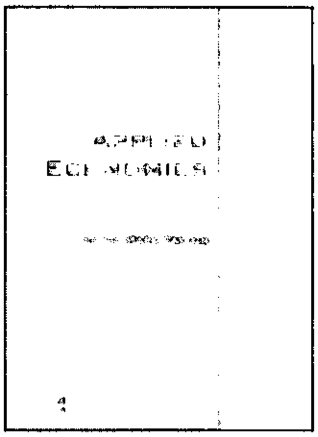

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Joint production and substitution in timber supply: a panel data analysis

Torjus F. Bolkesjø [a]; Joseph Buongiorno [b]; Birger Solberg [a]
[a] Department of Ecology and Natural Resource Management, Norwegian University of Life Sciences, Norway [b] Department of Forest Ecology and Management, University of Wisconsin-Madison, Madison, WI 53706, USA

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