Abstract

The long cycle of hardwood lumber production causes lagged response of supply, and lag effects can considerably affect the coefficients of simultaneous equations models in the long-run. This paper estimates a dynamic simultaneous equations model that represents the delayed response of demand and supply of U.S. hardwood lumber with lags of variables. The results show the hardwood lumber supply is price elastic in the long-run but price inelastic in the short-run. The price elasticity of lumber demand is inelastic in both the long-run and short-run.

Keywords: ECM, hardwood lumber, elasticity, short-run, long-run

Introduction

Hardwood lumber is an important industrial material. Unlike softwood lumber, which is primarily used in housing construction, hardwood lumber is used in manufacturing a variety of products such as furniture, cabinets, wood flooring, windows, doors, pallets, railway crossties, and many other miscellaneous items. There are a few studies published on the demand and supply of the U.S. hardwood market (e.g. Luppold 1984; Adams and Haynes 1996). Similar to most of the early models (Buongiorno et al. 1979, Adams and Haynes 1980, Newman and Wear 1993, Lewandrowski et al. 1994), past hardwood lumber models, from which the elasticities were obtained, failed to account for lag effects of the long-run coefficient. Such omissions could significantly alter the long-run coefficients.

Recently, Hsiao (1997a, 1997b) showed that a dynamic simultaneous equations model can be estimated by 2SLS or 3SLS technique consistently if sufficient cointegration relations exist. An error correction model (ECM) representing long-run and short-run relations can be obtained by transforming the estimated dynamic model.

The purpose of this study is to determine the long-run and short-run price elasticities of U.S. hardwood lumber demand and supply by transforming the estimated dynamic model into a restricted ECM following the method suggested by Hsiao (1997a, 1997b). The theoretical demand and supply equations will be derived with Cobb-Douglas technology and estimated simultaneously.

Methods

With simultaneous equations, the 2SLS technique will be applied. When the exogenous variables in a structural model are nonstationary, the model that generates the endogenous variables can be a vector of restricted autoregressive linear equations

\[ \Gamma(L)y_t + B(L)x_t = \varepsilon_t, \]  

(1)

where \( \Gamma(L) \) and \( B(L) \) are matrixes of functions of the lag operator \( L \). Some elements of matrixes are zeros as restrictions for the structural model. \( y_t \) and \( x_t \) are vectors of 2 endogenous (lumber production and price) and \( K \) exogenous variables respectively. \( \varepsilon_t \) is a 2 dimension vector of stationary error terms with mean zero. The corresponding error correction model for model (1) is

\[ \Gamma^*(L)\Delta y_t + B^*(L)\Delta x_t + \Gamma(1)y_{t-1} + B(1)x_{t-1} = \varepsilon_t. \]  

(2)

In this model \( \Gamma^*(L) \) and \( B^*(L) \) are matrixes including short-run coefficients. \( \Gamma(1) \) and \( B(1) \) are calculated from \( \Gamma(L) \) and \( B(L) \) when \( L = 1 \). \( \Delta y_t = y_t - y_{t-1}, \Delta x_t = x_t - x_{t-1} \), and \( \Delta = 1-L \). When the roots of \( |\Gamma(L)| = 0 \) lie outside the unit circle, the inverse \( \Gamma(L)^{-1} \) exists (Hamilton 1994). Therefore, \( y_t \) is a function of \( x_t \), and

\[ y_t = -\Gamma(L)^{-1}B(L)x_t + \Gamma(L)^{-1}\varepsilon_t. \]  

(3)

When \( \varepsilon_t \) is stationary and \( \Gamma(L)^{-1} \) exists, the error term \( \Gamma(L)^{-1}\varepsilon_t \) of the above equation are stationary. Equation (3) represents long-run relations at equilibrium, and \( -\Gamma(L)^{-1}B(L) \) produces a matrix of long-run coefficients.

Models

In 2002, about half of the hardwood lumber was used in manufacturing wood products such as pallets, crossties, and other miscellaneous uses, and the other half of hardwood lumber was used in manufacturing furniture and other home related wood products. Therefore, the manufacturing industry covers almost all of the wood products and is the driving force of hardwood lumber demand. In recent years, the international market for hardwood lumber has become more and more important. The percentage of exported hardwood lumber increased from 1.5% in 1965 to 10.4% in 2002. As such, export has to be taken into account, and domestic consumption is obtained by taking out net hardwood export from hardwood lumber production.

With Cobb-Douglas technology for the manufacturing industry, the lumber demand equation derived by applying the Shephard lemma to the Cobb-Douglas cost function can be transformed into a log-linear equation (Rockel and Boungiorno 1982, Adams et al. 1992). The elasticities are constant with such a technology. Therefore the elasticities estimated with such a model are for the whole historical data period rather than current elasticities. The derived hardwood lumber demand \( L_{um,t} \) will be a function of the hardwood lumber price \( P_{lum,t} \), prices of substitutes and complements, and the manufacturing output \( M_{ft} \). The prices of substitutes and complements are the price of plastic \( P_{pla,t} \) for non-wood materials, price of hardboard, particle board and fiber board products \( P_{boa,t} \) for wood substitutes, price of electricity \( P_{ele,t} \) for energy, and interest rate
(P_{cap,i}) for capital. Metal is another common substitute for wood in many cases. However, with a correlation coefficient of 0.98 between the prices of metal and plastic for the data period, metal price is excluded. The plastic price is used as a proxy for non-wood substitutes including metal. The log-linear equation for lumber demand derived from Cobb-Douglas can be written as:

$$\ln L_{tim} = \alpha_0 + \sum_j \alpha_j \ln P_{j,t} + \alpha_{mf} \ln Mf_t + \alpha_{lum} \ln L_{t-1} + \alpha_T t + \epsilon_{d,t},$$  \hspace{1cm} (4)

where $L_{tim}$ is the lumber consumption at time $t$, $\alpha_0$, $\alpha_j$, $\alpha_{mf}$, $\alpha_{lum}$, and $\alpha_T$ are parameters, and subscript $j = lum, pla, ele, boa, or cap$. Term $\alpha_T$ represents technological progress over time. The $\epsilon_{d,t}$ is an error term. One lag of the lumber consumption is included to eliminate possible autocorrelation. As a demand function, the above equation has to be homogeneous of degree zero in prices of hardwood lumber and other inputs of the manufacturing industry, non-increasing in own-price, and non-decreasing in outputs. These conditions require

$$\sum_j \alpha_j = 0, \hspace{0.5cm} \alpha_{lum} \leq 0, \hspace{0.5cm} \text{and} \hspace{0.5cm} \alpha_{mf} \geq 0.$$

The lumber supply function can be derived by applying the Hotelling’s lemma to the profit function of lumber production with a Cobb-Douglas technology. The log transformed lumber supply equation can be expressed as

$$\ln L_{tim} = \beta_0 + \beta_{lum} \ln P_{lum,t} + \beta_{lum1} \ln P_{lum,t-1} + \sum_k \beta_k \ln P_{k,t} + \beta_{lum} \ln L_{t-1} + \beta_T t + \epsilon_{s,t}.$$  \hspace{1cm} (5)

where ‘$\beta$’s are coefficients, and $\epsilon_{s,t}$ is a stationary disturbance term. $P_{k,t} = P_{lg,b}, P_{ele,b}, P_{cap,b}$ or $P_{ws,t}$ with $k = lg, ele, cap, or ws$ representing the prices of logs, electricity, interest rate, or wage rate of sawmills respectively. The sawmill inventory of lumber fluctuates with changes in current production and shipment which are determined by the lumber price when other variables are held constant. Therefore, inventory is endogenous and its effect can be covered by lagged price and supply of hardwood lumber. The lag terms will eliminate the possible autocorrelation caused by inventories and other factors. In the long-run the supply equation (4) is homogeneous of degree zero in prices, and a restriction

$$\beta_{lum} + \beta_{lum1} + \sum_k \beta_k = 0$$

will be imposed when the supply equation is estimated.

Equations (4) and (5) will be estimated simultaneously. In this simultaneous equations model the hardwood lumber production $L_{tim}$ and the lumber price $P_{lum,t}$ are endogenous variables, and all other variables are exogenous variables that will be used as instrument variables for the 2SLS estimation. The rank condition described by Hsiao (1997a, 1997b) is the same as those in textbooks (Greene 2002, Chapter 15), so the conventional rank condition is used to identify supply and demand equations. Since each equation has its unique variables that are not included
in the other equation, the rank condition is satisfied, and both equations (4) and (5) are identified. According to Hsiao (1997a, 1997b), when a dynamic model is identified, its corresponding equation in ECM is also identified. Thereby, the equations in the form of equation (2) derived from dynamic equation (4) and (5) are also identified.

Estimation

Annual data from 1965 to 2002 are used to estimate the simultaneous equations model. Data are mainly from Howard (2003), U.S. Department of Labor, Department of Energy Energy Information Administration, and the U.S. Federal Reserve Bank of St. Louis. The observed value for the hardwood lumber consumption \((Lum_t)\) is the U.S. “final hardwood production” by Howard (2003) minus the net export that is the difference between the export and import. The hardwood stumpage price is used as a proxy for the price of logs. The USDA miscellaneous publication No. 1357 is used as the sawmill labor price. The price data are first transformed into real prices by producer’s price index \(PPI_t\) if they are current prices. All the real prices, nominal interest rates, and quantities are then transformed by logarithm.

Augmented Dickey-Fuller and Phillips-Perron unit root tests with the transformed data showed that all the transformed data series used in equations (4)—(5) have unit roots and therefore, are non-stationary. With hardwood lumber price and production as the endogenous variables and the others as the exogenous variables, a cointegration test with a partial model (Johansen 1992) showed that the data series used in the simultaneous equations model have two cointegration relations. This result implies that it is possible to estimate equations (4) and (5) consistently with the 2SLS technique. Restriction of homogeneous of degree zero in prices is applied to both of the equations. The estimated coefficients are shown in Table 1.

The price of electricity and capital (interest rate \(P_{cap}\)) in the supply equation are restricted to be zero since the significant levels of these two coefficients are close to 1 when they are not constrained. \(\chi^2\) tests for the restrictions on these equations show that the hypotheses on these restrictions cannot be rejected.

All the estimated coefficients of the demand equation are significant at 5% level, and all the estimated coefficients of the supply equation but that of sawmill wage rate are significant at 1% level. The coefficient of the sawmill wage rate in the supply equation is significant at 14% level.

The corresponding \(B(L)\) is the transpose of the coefficient matrix of the predetermined variables from \(lnP_{pla,t}\) down to \(ln(P_{lum,t})\) is not a predetermined but an endogenous variable) in Table 1. There is no lags of these predetermined variables, so there is no \(L\) in \(B(L)\); therefore, \(B(1) = B(L)\). \(\Gamma(L)\) is formed by coefficients of endogenous variables. These coefficients are functions of \(L\) whenever lags of the corresponding endogenous variable exist. The roots of equation \(|\Gamma(L)| = 0\) are 1.311 and 5.172 that are outside the unit circle. These roots imply that the lag structure of the estimated model is stationary.

The coefficients of each variable and its lag are first summed to obtain an element in \(\Gamma(1)\) and \(B(1)\), then the coefficients of \(lnLum_t\) in both equations are normalized to -1 to get the estimated
long-run demand and supply equations corresponding to equation (4) and (5). The long-run coefficients are presented in Table 2.

Table 1. Estimated results with the 2SLS technique

<table>
<thead>
<tr>
<th>Variables</th>
<th>Demand ((\ln L_{um,t}))</th>
<th>Supply ((\ln L_{um,t}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficients</td>
<td>Significant level</td>
</tr>
<tr>
<td>(\ln P_{lum,t})</td>
<td>-0.241</td>
<td>0.00</td>
</tr>
<tr>
<td>(\ln P_{lum,t-1})</td>
<td>-0.546</td>
<td>0.00</td>
</tr>
<tr>
<td>(\ln P_{lg,t})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\ln P_{pla,t})</td>
<td>0.102</td>
<td>0.04</td>
</tr>
<tr>
<td>(\ln P_{ele,t})</td>
<td>-0.131</td>
<td>0.00</td>
</tr>
<tr>
<td>(\ln P_{boa,t})</td>
<td>0.335</td>
<td>0.00</td>
</tr>
<tr>
<td>(\ln P_{cap,t})</td>
<td>-0.064</td>
<td>0.05</td>
</tr>
<tr>
<td>(\ln P_{ws,t})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\ln M_{f,t})</td>
<td>0.646</td>
<td>0.00</td>
</tr>
<tr>
<td>(\text{Constant})</td>
<td>4.476</td>
<td></td>
</tr>
<tr>
<td>(T)</td>
<td>-0.0091</td>
<td>0.00</td>
</tr>
<tr>
<td>(\ln L_{um,t-1})</td>
<td>0.265</td>
<td>0.00</td>
</tr>
<tr>
<td>(R^2)</td>
<td>0.91</td>
<td></td>
</tr>
<tr>
<td>(\chi^2) for restrictions</td>
<td>0.96</td>
<td>0.33</td>
</tr>
</tbody>
</table>

After normalization, the coefficients for the prices in the “after normalization” columns of Table 2 are also long-run elasticities because the variables are log-transformed. The estimated long-run price elasticity of hardwood lumber demand is -0.328. Prices of plastic \(P_{pla,t}\) and composite board \(P_{boa,t}\) have positive coefficients. These coefficients imply that both wood and non-wood substitutes have significant substitution effects on hardwood lumber. The prices of electricity and interest rates have negative coefficients implying that power and capital are complements of hardwood lumber. The coefficient of manufacturing production is 0.879 and less than 1, meaning that the lumber demand will only grow 87.9 percent for every one percent increase in manufacturing production. This simply suggests that the demand for hardwood lumber grows slower than the manufacturing industry does. Although the sum of estimated coefficients of the current and lagged lumber prices in the supply equation is only 0.194, the cumulative effect in the long-run hardwood supply (after normalization) is 1.037, showing the significant impact from the lagged dependent variable. Consequently, the derived price elasticity of the long-run supply (1.037) is greater than unit, suggesting that the hardwood lumber supply is price elastic in the long-run. This long-run price elasticity is larger than those from the previous studies that overlooked the lag effects. The long-run log price elasticity of lumber supply is 0.278, implying that the lumber supply is inelastic to a log price change.

The short-run coefficients of the ECM in the form of model (2) can be obtained by transforming the estimated dynamic model (1) that includes equations (3) and (4). Let the equilibrium errors of
the two equations be $Z_d$ and $Z_s$, then:

$$Z_d = \ln L_{um,t} - (6.090 - 0.328 \ln P_{lum,t} + 0.139 \ln P_{pla,t} - 0.178 \ln P_{ele,t} + 0.456 \ln P_{hoa,t}$$

$$- 0.087 \ln P_{cap,t} + 0.879 \ln M_f - 0.012 t )$$

$$Z_s = \ln L_{um,t} - (8.572 + 1.037 \ln P_{lum,t} - 0.278 \ln P_{th,t} - 0.759 \ln P_{ws,t} + 0.023 t ).$$

Table 2. Transformed long-run coefficients

<table>
<thead>
<tr>
<th>Variables</th>
<th>Demand equation</th>
<th>Supply equation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td></td>
<td>normalization</td>
<td>normalization</td>
</tr>
<tr>
<td>$\ln L_{um,t}$</td>
<td>-0.735</td>
<td>-1</td>
</tr>
<tr>
<td>$\ln P_{lum,t}$</td>
<td>-0.241</td>
<td>-0.328</td>
</tr>
<tr>
<td>$\ln P_{lg,t}$</td>
<td>0.102</td>
<td>0.139</td>
</tr>
<tr>
<td>$\ln P_{pla,t}$</td>
<td>-0.131</td>
<td>-0.178</td>
</tr>
<tr>
<td>$\ln P_{ele,t}$</td>
<td>0.335</td>
<td>0.456</td>
</tr>
<tr>
<td>$\ln P_{boa,t}$</td>
<td>-0.064</td>
<td>-0.087</td>
</tr>
<tr>
<td>$\ln P_{cap,t}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\ln P_{ws,t}$</td>
<td>4.476</td>
<td>1.603</td>
</tr>
<tr>
<td>constant</td>
<td>-0.0091</td>
<td>-0.012</td>
</tr>
</tbody>
</table>

The two equations of the transformed ECM are

Demand:

$$\Delta \ln L_{um,t} = -0.0091 - 0.241 \Delta \ln P_{lum,t} + 0.102 \Delta \ln P_{pla,t} - 0.131 \Delta \ln P_{ele,t} + 0.335 \Delta \ln P_{hoa,t}$$

$$- 0.064 \Delta \ln P_{cap,t} + 0.646 \Delta \ln M_f - 0.735 Z_{d,t} + \varepsilon_{d,t}$$

Supply:

$$\Delta \ln L_{um,t} = -0.0043 + 0.740 \Delta \ln P_{lum,t} - 0.052 \Delta \ln P_{th,t} - 0.142 \Delta \ln P_{ws,t} - 0.187 Z_{s,t} + \varepsilon_{s,t}.$$ 

In the estimated ECM equations $\varepsilon_{d,t}$ and $\varepsilon_{s,t}$ are corresponding error terms. The first equation is for the hardwood lumber demand, and the second equation is for the hardwood lumber supply. The coefficient -0.735 of $Z_d$ implies that the equilibrium error of demand of hardwood lumber is adjusted 73.5 percent in the next year; and the coefficient -0.187 of $Z_s$ implies that the equilibrium error of the hardwood lumber supply is adjusted only 18.7 percent in the next year. The coefficients of the differenced variables are the corresponding short-run elasticities. The short-run price elasticities of lumber demand and supply are -0.241 and 0.740 respectively. All the other short-run coefficients of demand are the same as their corresponding coefficients in the estimated dynamic model. The short-run coefficient of log price in the lumber supply equation is close to zero (-0.052). The short-run coefficient for the sawmill wage rate in the supply equation
is -0.142. These elasticities equal the current year coefficients and represent the current year responses of lumber demand and supply to changes in prices.

Discussion and Conclusions

With lag variables in the hardwood lumber demand and supply equations the estimated short-run and long-run elasticities are quite different. The estimated one year own-price elasticity of hardwood lumber supply is 0.740, in two years it is 0.194, but in the long-run it is 1.037. Empirically this result is easy to understand. It usually takes 9 to 12 months for green hardwood lumber to be dried before being shipped to consumers. Some drying methods dry lumber faster with a higher cost, and others like air drying take a longer time with a lower cost. When the lumber price is high, more wood will be dried by faster methods, and more lumber will be shipped in the current year. However, the lumber output will decrease in the second year because some of the lumber scheduled for that year had been shipped earlier. As a result, an increased price has a negative effect on the lumber supply in the second year. Therefore, hardwood lumber supply has a larger elasticity in one year but a smaller elasticity in two years.

When the lumber price stays at a high level in the long-run, sawmills are able to recover their inventory and invest more in hardwood production to enlarge capacity. The large coefficient (0.813) of lagged lumber supply suggests that it takes a long time for sawmills to increase hardwood lumber capacity. In the long-run, the effect of a high lumber price on the supply of hardwood lumber is significant, and the long-run hardwood lumber supply is price elastic with elasticity 1.037.

The estimated demand equation has a smaller coefficient of the lagged hardwood lumber consumption. Consequently, the long-run and short-run price elasticities of hardwood lumber demand are quite close (-0.328 and -0.241).

Based on the estimated results, hardwood lumber demand is driven by the manufacturing industry but the technological progress reduces consumption of hardwood lumber over time. The main substitutes for hardwood lumber are other wood products.

The meaning of short-run elasticity from an ECM is not the same as that defined in microeconomics textbooks. With ECM, the short-run elasticity implies the response of the dependent variable to a change in an independent variable in one year. On the other hand, the short-run elasticity in a microeconomics textbook represents the percentage change of the dependent variable as a result of a one percent change in the price of a factor when some other factors do not have time to respond to the change. Such a definition is theoretically clear but empirically not as useful as the short-run elasticity in an ECM, since the textbook definition could not tell how long a short-run response will take.

Literature Cited


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