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The Effect of Changes in Lumber and Furniture Prices on Wood Furniture Manufacturers' Lumber Usage

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Abstract

Wood furniture manufacturers' demands for oak, maple, poplar, open-grain, and close-grain lumber are estimated using cross-sectional, time-series techniques. The analyses indicate that the demand for open-grain species is more price responsive than the demand for close-grain species. The calculated cross-price elasticities indicate that furniture producers do substitute species through style decisions. However, poplar lumber has a negative cross-price elasticity, indicating that it is used with, rather than substituted for, other species.

Introduction

Wood furniture manufacturers are the major demanders of higher grade hardwood lumber; they use more than 24 percent of all hardwood lumber consumed in the United States. Because furniture demand is expected to increase as the "baby boom" generation establishes new households, demand for hardwood lumber by wood furniture manufacturers is expected to increase. This could lead to significantly increased lumber prices if current conditions in the hardwood lumber market persist.

One major problem within the hardwood lumber market is lack of information on the inner workings of the market itself. Inadequate information makes markets inefficient because productive resources tend to be poorly allocated. Poor allocation of productive resources increases production costs and leads to increased consumer prices. The objective of this study is to provide some of this much needed information by quantifying the relationship between furniture manufacturers' demand for hardwood lumber and the prices of hardwood lumber and furniture.

Such information would benefit lumber distributors, the furniture industry, and furniture consumers. Lumber distributors (producers and wholesalers) could use such information to better anticipate current and future demands for various species of hardwood lumber. The furniture industry would benefit from the actions of lumber distributors because adequate supplies would more likely be available at the time they are needed. Consumers would benefit from the eventual decrease in the relative price of furniture.

Model Development

Wood furniture manufacturers use many different species of hardwood lumber. The amount of a particular species used by a manufacturer is dependent on the price category and style of furniture being produced and the price of furniture in general. The price of one species may affect the demand for, or usage of, another species because of the relationship between past lumber prices and current styles being introduced at the furniture markets. Of course, this relationship is much weaker for a manufacturer specializing in high-priced 18th century reproductions than for a manufacturer producing several lines of popular-priced furniture.

In this study, the quantity of hardwood lumber of a particular species demanded by a furniture manufacturer is assumed to be affected by: (1) the past prices of lumber of that species (own price), (2) the past prices of complementary and substitute species (cross price), (3) the wholesale price of furniture and (4) past quantity of lumber demanded.

Lagged quantity is included in the model as an aggregation variable. This allows the demands of firms of various sizes to be estimated in the same equation. This variable also accounts for style expectations, since past lumber use is representative of past furniture styles produced by the firm.

The major variables included in the general model and the expected relationships between the variables and the quantity demanded are specified in Table 1. This general specification is the basis for all estimated demand equations presented in the next section.

Table 1.—The major factors, variables, expected relationships between variables and quantity demanded, and units for furniture manufacturers' lumber demand equations

Factor	Variable	Expected relation	Units
Lumber price of the species being demanded	Price index of lumber of the species being demanded, lagged 1-1/2 years (own price)	Negative	Index (1974 = 100)
Lumber price of substitute or complementary species	Weighted price index of substitute or complementary species, lagged 1-1/2 years (price of substitutes, complements)	Positive (substitute) Negative (complement)	Index (1974 = 100)
Wholesale price of wood furniture	An index of the wholesale price of furniture (furniture price)	Positive	Index (1967 = 100)
Lagged quantity	Quantity of lumber of the species being demanded, lagged 1 year (lagged quantity)	Positive	Million board feet

Specification of Substitute and Complement Price Variables

Since each estimated equation represents the demand by furniture manufacturers for a specific species of lumber, the variable representing the price of substitutes or complementary species is different for each equation. The variable representing the price of substitute species in the oak equation is the weighted price index of ash, pecan, elm, hackberry, maple, and white pine lumber. These species have some characteristics that may encourage a manufacturer to use them, rather than oak, when designing a suite. The first four species are chosen because they have an open grain. Maple is included because it and oak are intermediate-priced species. White pine is included because it is a substitue for oak in heavy, "over designed" furniture.

The variable representing price of substitute lumber in the maple equation is the weighted price index of cherry, gum, and oak lumber. It is felt that these species have certain characteristics that allow them to be substituted for maple. Cherry and gum are close-grain species with some characteristics similar to maple lumber, while both oak and maple are intermediately priced.

The cross-price variable for open-grain lumber contains the weighted price index of all lumber not considered open grain. While the price of substitute lumber in the close-grain equation is the weighted price index of all non-close grain lumber, no cross-price variable is included in the demand for all lumber because the weighted price of all species of lumber is included in the own-price variable.

The weighted price index of all species other than poplar is used as the price of complements in the poplar demand model. We assume that poplar is used with, rather than substituted for, other species of lumber. It should be noted that the data base for the poplar demand equation does not contain any promotional furniture producers. Promotional furniture producers use poplar in exterior parts and may substitute poplar lumber for sweet gum, black gum, or other inexpensive woods that can be easily embossed.

Data Base

The quantity data used in this paper were originally collected for a study of wood furniture manufacturers' demands by Luppold (1981). These data consist of lumber usage statistics, by species, for the years 1974 through 1979 by 11 wood furniture producers. These producers employed 250 or more production workers each and were located in Virginia, North Carolina, and South Carolina. All firms included in the final sample produced several different lines of furniture and used several different species of hardwood lumber. Lumber price data were obtained from the *Hardwood Market Report* (Lemsky 1972–1978) and wood furniture price data were collected from *Wholesale Prices and Price Indexes* (U.S. Department of Labor 1974–1979).

The firms included in the data base are representative of the larger wood furniture manufacturers in the Southeast. Wood furniture firms in this region account for more than 50 percent of the national production, and firms employing 250 or more workers account for about 75 percent of the materials used in wood furniture manufacturing (U.S. Department of Commerce 1980).

Equation Estimation

Demand relationships were estimated for oak, maple, and poplar lumber, as well as for open-grain lumber, close-grain lumber, and all lumber as an aggregate. These estimated relationships are presented and compared in this section.

Since the data base consists of lumber usage over time by several firms, the equations were estimated by the ordinary least squares (OLS) and cross-sectional time-series (CSTS) techniques. Results from both estimation procedures are presented to show the advantages and disadvantages of each technique. The Parks (1967) cross-sectional time-series algorithm was used because it accounts for contemporaneously correlated errors between cross sections that may result from the omission of unknown or unmeasurable variables. The Parks method also adjusts for autocorrelation within time series and heteroskedasticity across cross sections. A rigorous development of the Parks method is presented in the Appendix.

Because pooled cross-sectional and time-series data are used, estimated responses to changes in prices (price elasticities) cannot be strictly interpreted as being either longrun or shortrun in nature. However, since there was much more variation in the prices over time than there was over the firms, the resulting elasticities are more representative of shortrun responses.

The results of the OLS estimates are presented in Table 2, while the CSTS estimates are presented in Table 3. The standard errors associated with almost all the parameters are reduced by as much as 94 percent by using the Parks estimation procedure. Further, the magnitudes of the coefficients do not differ significantly between the OLS estimates and the CSTS estimates except for the maple model. The decrease in standard error without a radical change in the magnitude of the estimated coefficients indicates that the Parks method did yield statistically more efficient estimates than did OLS.

Table 2.—Ordinary least squares estimates of wood furniture manufacturers' demand for hardwood lumber, by species, 1975-1979 (standard errors in parentheses)

	Oak lumber	Maple lumber	Poplar lumber	Open grain lumber	Close grain lumber	All lumber
Intercept	– 3832	– 2318	– 1487	– 3124	– 3140[d]	– 5337
	(3139)	(3254)	(2137)	(4032)	(2929)	(5737)
Own price	– 32.61[d]	79.24	– 8.56	– 38.02[d]	– 5.47	– 15.66
	(26.86)	(60.72)	(13.98)	(34.60)	(5.01)	(60.54)
Price of substitutes and complements	59.64[a]	– .628	– 11.64	23.19	– .218	NA
	(22.91)	(13.67)	(18.64)	(35.34)	(20.98)	
Price of furniture	5.03	– 1.43	20.9[c]	27.3	23.6[c]	44.0[d]
	(29.1)	(24.6)	(14.8)	(27.8)	(18.1)	(32.6)
Lagged quantity	.857[a]	.816[a]	1.006[a]	.959[a]	.963[a]	.967
	(.065)	(.179)	(.039)	(.043)	(.062)	(.032)
R^2	.905	.599	.954	.935	.911	.958
F-value	59.6	7.50	183	127	64.4	309
Degrees of freedom	25	20	35	35	25	40
Mean quantity (Mbf)	5470	1590	3300	7669	3224	16148

[a] = Significant at the .01 level.
[b] = Significant at the .05 level.
[c] = Significant at the .10 level.
[d] = Significant at the .15 level.
NA = Not applicable.

Table 3.—Cross-sectional time-series results of wood furniture manufacturers' demand for hardwood lumber, 1975-1979 (standard errors in parentheses)

	Oak lumber	Maple lumber	Poplar lumber	Open grain lumber	Close grain lumber	All lumber
Intercept	– 3398[a]	– 902[c]	1896[b]	– 4219[a]	– 3096[a]	– 6569[a]
	(821)	(681)	(1051)	(861)	(934)	(1400)
Own price	– 35.80[a]	– 12.82[b]	– 11.63[b]	– 39.31[a]	– 6.27[a]	– 15.66[a]
	(6.58)	(6.38)	(5.88)	(5.75)	(.854)	(3.52)
Price of substitutes and complements	35.76[a]	2.56[b]	– 8.49[b]	40.96[a]	7.76[b]	NA
	(8.14)	(1.44)	(4.35)	(6.85)	(4.14)	
Price of furniture	17.4[a]	13.2[a]	22.7[a]	23.6[a]	20.3[a]	45.8[a]
	(4.78)	(4.75)	(5.12)	(5.10)	(6.29)	(11.8)
Lagged quantity	.941[a]	.964[a]	1.024[a]	1.01[a]	.898[a]	.994[a]
	(.019)	(.058)	(.048)	(.011)	(.070)	(.006)
Degrees of freedom	25	20	35	35	25	40
Mean quantity (Mbf)	5470	1590	3300	7669	3224	16148

[a] = Significant at the .01 level.
[b] = Significant at the .05 level.
[c] = Significant at the .10 level.
[d] = Significant at the .15 level.
NA = Not applicable.

Interpreting the Results

The effect of changes in lumber or furniture price on quantity of lumber demanded is exhibited in Table 4 in the form of price elasticities. These elasticities indicate the percentage change in quantity demanded resulting from a 1-percent change in price. Own-price elasticity represents the effect of a change in price of a particular species on the demand for that species, while cross-price elasticity represents the effect of a change in prices of other species.

As previously mentioned, the elasticities are more representative of shortrun responses to changes in prices, since most of the variation in the data base occurred in the time-series data rather than in the cross-sectional data. Since furniture producers respond to past lumber prices and current furniture price, the estimated lumber-price elasticities are indicative of the likely response 1 to 2 years after a change in lumber price, and the furniture-price elasticity represents the response in the current year to a change in furniture price.

In general, open-grain lumber was found to be more price-elastic with respect to its own price and the price of substitutes, and less price elastic with respect to furniture price than was close-grain lumber. One exception to this rule was maple, which had the highest own-price elasticity and the lowest furniture-price elasticity. These results indicate that open-grain lumber demand is more affected by lumber price and close-grain lumber demand is more affected by furniture price.

Another general observation that can be made is that the cross-price elasticities are nearly as high or higher than the own-price elasticities in the oak, open-grain, close-grain, and poplar equations. This indicates that prices of other lumber, when taken as a group, affect demand for a particular species by about the same amount as the price of that species. Again, one exception to this rule is maple, which appears to have a very low cross-price elasticity.

The estimated cross-price elasticity of poplar is negative. This finding supports the hypothesis that poplar is a complement to other lumber and not a substitute. The low own-price elasticity was also expected, since poplar is used as an interior lumber with a number of different exterior species.

The own-price elasticity for all lumber demanded is −.09, which is quite low. This is not surprising since wood furniture manufacturers must use wood. The furniture-price elasticity of .49 is also quite low when compared with the demand equations for the different species.

The elasticities calculated from the estimated maple demand equation are much different for the elasticities of the other equations. These results may be due to some peculiar characteristics of maple, but also may result from the relatively poor statistical fit of the maple equation. The OLS estimates for the maple equation had a low R^2 and incorrect signs for three of the four nonintercept variables. Although the CSTS results had the correct signs on all variables, the standard errors associated with the estimated parameters were relatively high.

Table 4.—Own-price, cross-price, and furniture-price elasticities for wood furniture manufacturers' demand for hardwood lumber, 1975–1979

Model	Own-price elasticity[a]	Cross-price elasticity	Furniture-price elasticity
Oak lumber	−.654	.743	.550
Maple lumber	−.867	.171	.143
Poplar lumber	−.295	−.282	1.18
Open-grain lumber	−.525	.566	.528
Close-grain lumber	−.265	.243	1.08
All lumber	−.087	NA	.488

[a] All elasticities were calculated at the means using the cross-sectional time-series parameter estimates, by the following formula:

$$\frac{\partial \text{ quantity demanded}}{\partial \text{ price}} \times \frac{\text{(mean of price)}}{\text{(mean of quantity demanded)}}$$

NA = Not applicable.

Implications

Two major implications of this study are: (1) past lumber and current furniture prices affect wood furniture manufacturers' demand for lumber, and (2) current demand for a particular species is affected by past prices of other species. With respect to the second implication, it should be noted that most furniture manufacturers do not directly substitute one species for another; rather, past lumber prices affect current design and style decisions. The degree to which past lumber prices affect current design varies from firm to firm. But the sizes of the estimated cross-price elasticities relative to the own-price elasticities indicate that large firms do consider past lumber prices when developing and promoting different styles of furniture.

Another implication is that wood furniture manufacturers' demand for hardwood lumber, as a whole, is quite inelastic with respect to the price of hardwood lumber. However, these manufacturers' demand for lumber of specific species or groups of species is much more elastic. Of the individual species and species groups, open-grain, oak, and maple lumber are more price-elastic than poplar and close-grain lumber.

Furniture manufacturers' demand for close-grain lumber is relatively inelastic with respect to the price of close-grain lumber and the price of substitute species, but is relatively elastic with respect to price of furniture. These results indicate that the demand for species used in traditional types of furniture, such as cherry and mahogany, is not greatly affected by the prices of substitute species, but is influenced by the price of wood furniture.

Maple lumber demand is different from the demand for other close-grain species in that maple demand is relatively price-elastic. However, demand for maple lumber is similar to the demand for close-grain species in that cross-price elasticity is relatively low and furniture-price elasticity is relatively high. These results may suggest that maple lumber demand is greatly affected by the price of maple lumber and the price of wood furniture, but these results must be interpreted with caution since the statistical fit of this equation was relatively poor.

The estimated results of the demand for open-grain lumber indicate little difference between own-price elasticity, cross-price elasticity, and furniture-price elasticity. This indicates that the price of open-grain lumber, the price of substitute species, and the price of furniture have about an equal effect on the demand for open-grain species.

Oak lumber demand is different from the demand for all open-grain species in that the absolute values of the cross-price and own-price elasticities are up to 35 percent larger than the furniture-price elasticity. However, the furniture-price elasticity for oak is very close to the furniture-price elasticity for all open-grain species. These results imply that the demand for oak lumber is more responsive to changes in the price of oak and other species than it is to changes in the price of furniture.

The estimated demand for poplar lumber indicates a relatively inelastic own-price elasticity and a relatively elastic furniture-price elasticity. The negative cross-price elasticity indicates that poplar lumber is used in conjunction with, rather than as a substitute for, lumber of other species. The results also indicate that poplar lumber demand is elastic with respect to the price of wood furniture.

Summary and Conclusions

Furniture manufacturers are the major demanders of higher grade hardwood lumber. Their demands are expected to increase in the future because of an expected increase in furniture demand. Increased lumber demand will inevitably lead to increased lumber price. The level lumber price will reach is uncertain since many factors affect it; however, increasing the efficiency of the hardwood lumber market would help to keep future price increases at a minimum.

One major ingredient of market efficiency is good market information. The objective of this study was to provide some of the needed information by developing and estimating relationships that measure the effect of lumber and furniture prices on wood furniture manufacturers' demand for lumber.

Equations representing furniture manufacturers' demands for oak, maple, poplar, open-grain, close-grain, and all varieties of lumber were estimated using OLS and CSTS techniques. The results indicate that wood furniture manufacturers do substitute species to reduce costs; but this substitution takes place over time and not immediately. Such substitutions will cause fluctuations in the prices of individual species rather than in the aggregate price of hardwood lumber.

Future analysis using cross-sectional time-series data from more firms and in separate regions would provide greater and more refined information on wood furniture manufacturers' lumber demands. Information pertaining to the substitution of other wood products and nonwood products for lumber would also be of great value in predicting future market behavior.

In conclusion, wood furniture manufacturers' demand for lumber of various species is price-sensitive. Lumber distributors should realize this before making long run commitments. Forest industry groups and policymakers should also realize the degree to which one species can substitute for another before advocating legislation aimed at ensuring adequate domestic supplies of any particular species.

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Appendix

The Parks Method of Cross-Sectional Time-Series Estimation

When equations are estimated with ordinary least squares and pooled cross-sectional and time-series data, the resulting parameter estimates are unbiased and consistent. However, these estimates may be inefficient because of the effects of autocorrelation and heteroskedasticity. The Parks method is an Aitken's generalized least square procedure that incorporates prior information of the disturbance term in the estimation of the parameters. The resulting parameter estimates have the properties of consistency, unbiasedness, asymptotic efficiency, and asymptotic normality.

The general form of a statistical model containing k variables and using pooled cross-sectional and time-series data can be expressed as:

$$Y_{it} = B_0 + B_1X_{it,1} + \ldots + B_kX_{it,k} + \varepsilon_{it} \quad [1]$$

$$(i = 1, \ldots, N)\ (t = 1, \ldots, T)$$

The sample data are represented by T time-series and N cross-sectional observations for a total of N × T observations. The statistical model can be expressed in matrix notation as follows:

$$Y = XB + \varepsilon \quad [2]$$

Where Y is an $(N \times T) \times 1$ vector of observations of the dependent variable, X is an $(N \times T) \times (k + 1)$ matrix of observations of predetermined variables, B is a $(k + 1) \times 1$ vector of parameters and ε is an $(N \times T) \times 1$ vector of disturbance terms. The ordinary least squares estimates for the model are:

$$B = (X'X)^{-1}X'Y \quad [3]$$

Given the general model, the following assumptions are made:

(i) $E(\varepsilon, \varepsilon^1) = \Omega$, where:

$$\Omega = \begin{bmatrix} E(\varepsilon_{11}^2) & \cdots & E(\varepsilon_{11}\varepsilon_{IT}) & \cdots & E(\varepsilon_{11}\varepsilon_{N1}) & \cdots & E(\varepsilon_{11}\varepsilon_{NT}) \\ \vdots & & \vdots & & \vdots & & \vdots \\ E(\varepsilon_{IT}\varepsilon_{11}) & \cdots & E(\varepsilon_{IT}^2) & \cdots & E(\varepsilon_{IT}\varepsilon_{N1}) & \cdots & E(\varepsilon_{N1}\varepsilon_{NR}) \\ \vdots & & \vdots & & \vdots & & \vdots \\ E(\varepsilon_{N1}\varepsilon_{11}) & \cdots & E(\varepsilon_{NT}\varepsilon_{IT}) & \cdots & E(\varepsilon_{N1}^2) & \cdots & E(\varepsilon_{N1}\varepsilon_{NT}) \\ \vdots & & \vdots & & \vdots & & \vdots \\ E(\varepsilon_{NT}\varepsilon_{11}) & \cdots & E(\varepsilon_{NT}\varepsilon_{IT}) & \cdots & E(\varepsilon_{NT}\varepsilon_{N1}) & \cdots & E(\varepsilon_{NT}^2) \end{bmatrix}$$

$$(N \times T) \times (N \times T)$$

(ii) the predetermined variables are nonstochastic and are independent of the disturbance term.

(iii) the number of observations exceeds the number of predetermined variables plus the intercept.

The specification of the behavior of the disturbance term for models estimated using time-series data pooled cross-section and time-series is:

(i) $E(\varepsilon_{it}^2) = \sigma_{ii}$

(ii) $E(\varepsilon_{it}\varepsilon_{jt}) = \sigma_{ij}$

(iii) $\varepsilon_{it} = \rho_i\varepsilon_{i,t-1} + \mu_{it}$

where:

$\mu_{it} \sim N(0, \phi_{ii})$

$E(\varepsilon_{i,t-1}\mu_{jt}) = 0$ for all i, j

$E(\mu_{it}, \mu_{jt}) = \phi_{ij}(i \neq j)$

$E(\mu_{it}, \mu_{js}) = 0(t \neq s)$

$i, j = 1, \ldots, N$

$t, s = 1, \ldots, T$

Condition (i) allows cross-sectional heteroskedasticity, condition (ii) allows mutual correlation of the disturbance term across cross sections and, condition (iii) permits a separate first-order autoregression scheme for each cross section. The autoregressive disturbance term, μ_{it}, is assumed to be normally distributed with a constant variance and zero covariance between time periods for the same cross-sectional unit (furniture firm). The autoregressive disturbances during the same time period are correlated across cross sections, but the autoregressive disturbance for firm i, in period t, and firm j, in period s, for s = t are assumed to be independent. Finally, $\varepsilon_{i,t-1}$, and μ_{jt} are assumed to be independent.

Given the specification of the behavior of the disturbance term, the following relationships can be developed:

(i) $E(\varepsilon_{it}^2) = \phi_{ii}/1 - P_i^2 = \sigma_{ii}$

(ii) $E(\varepsilon_{it}\varepsilon_{jt}) = \phi_{ij}/1 - \rho_i \rho_j = \sigma_{ij}$

(iii) $E(\varepsilon_{it}\varepsilon_{is}) = \rho_i^{t-s}\sigma_{ii}$ if t is greater than s

(iv) $E(\varepsilon_{it}, \varepsilon_{js}) = \rho_i^{t-s}\sigma_{ij}$ (i = j)

$i,j = 1, \ldots, N$

$t,s = 1, \ldots, T$

The initial disturbance term, ε, associated with the pooled cross-sectional time-series data is assumed to have the following properties:

$$\varepsilon_{ia} \sim N(0,\phi_{ii}/1 - \rho_i^2)$$

$$E(\varepsilon_{ia}\varepsilon_{ja}) = \phi_{ij}/1 - \rho_i \rho_j$$

The matrix for the Parks model is:

$$\Omega = \begin{bmatrix} \sigma_{11}P_{11} & \ldots & \sigma_{1N}P_{1N} \\ \sigma_{N1}P_{N1} & \ldots & \sigma_{NN}P_{NN} \end{bmatrix}$$

$$(N \times T) \times (N \times T)$$

where:

$$P_{ij} = \begin{bmatrix} 1 & \rho j & \ldots & \rho^{T-1} \\ \rho_i & 1 & \ldots & \rho_j^{T-2} \\ \rho_i^{T-1} \rho_i^{T-2} & & \ldots & 1 \end{bmatrix}$$

$$(T \times T)$$

The Parks method estimates an Ω matrix by first estimating a value for ρ_i from an ordinary least square estimate. Using ordinary least squares, the following equation is estimated:

$$Y_{it}^* = B_0^* + B_1^*X_{1t}^* + \ldots + B_k^*X_{it}^* + \mu_{it}^* \qquad [4]$$

where:

$Y_{it}^* = Y_{it} - \rho_i Y_{i,t-1}$

$X_{it,k}^* = X_{it,k} - \rho_i X_{i,t-1,k} (k = 1, \ldots, k)$

$B_0^* = B_0(1 - \rho_i)$

$\mu_{it}^* = \varepsilon_{it} - \rho_i \varepsilon_{i,t-1}$

$t = 2, \ldots, T$

$i = 1, \ldots, N$

From the residuals of the above estimation, μ_{it}^* is calculated.

From these residuals, estimates of ϕ_{ii}, ϕ_{ij}, σ_{ii}, and σ_{ij} are obtained by:

$\phi_{ii} = (1/T - k - 1)\,\Sigma\, \mu_{it}^{*2}$

$\phi_{ij} = (1/T - k - 1)\,\Sigma\, \mu_{it}^* \mu_{jr}^*$

$\sigma_{ii} = \sigma_{ii}/1 - \rho_i^2$

$\sigma_{ij} = \phi_{ij}/1 - \rho_i \rho_j$

This procedure yields consistent estimates of σ_{ii} and σ_{ij}, therefore, a consistent estimate of Ω is obtained. Finally, using the Aitken's procedure,

$$B = (X'\tilde{\Omega}^{-1}X)^{-1}(X\Omega^{-1}Y) \qquad [5]$$

where $\tilde{\Omega}$ is a consistent estimator for Ω. The asymptotic variance-covariance matrix of B is:

$$\text{Var-Cov}(B) = (X'\tilde{\Omega}^{-1}X)^{-1} \qquad [6]$$

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