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SUBSTITUTION BETWEEN WOOLS OF DIFFERENT FIBRE DIAMETER*

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The extent to which wools with different fibre characteristics can be substituted in textile production and consumption holds implications for Australia's international and domestic marketing policies. An analysis of price-induced substitution between Australian wools of different fibre diameters was conducted. Fibre diameter was used to parameterise cross-price relationships in order to estimate a system of demand equations for wools by diameter class. The results indicate that direct substitution takes place within a very limited range of fibre diameters. The use of product characteristics to parameterise price relationships may be extended to other graded commodities.

The degree to which fibres can be substituted in textile production and consumption is an important factor influencing the demand for raw wool in Australia. Substitution can relate to competition between different grades of Australian wool and those produced by other exporters as well as competition between wool, synthetic and other natural fibres. The subject of this paper is the price-induced substitution relationships between Australian wools of different fibre diameters.

Wool varies in a wide range of attributes which affect its processing characteristics and the quality of final products. Fibre diameter is the most important physical attribute of wool, as it closely governs the spinning capacity, strength and texture of yarns (Skinner 1965). Fibre diameter is inversely related to other important physical characteristics of raw wool, such as fibre length and strength. The demands for different grades of wool are closely related, but different grades are not perfect substitutes. Substitution in the production and consumption of textile products is reflected in relative price movements which occur in response to shifts in wool supplies and in the demand for final products.

Substitution between wools of different fibre diameter has direct implications for Australia's international and domestic marketing policies. Richardson (1981) discusses a number of implications of imperfect substitution between domestic wools for the efficient operation of the reserve price scheme. Issues regarding appropriate levels of price stabilisation for various wool types and the composition of stocks held by the Australian Wool Corporation depend, in part, on the extent of substitution within domestic wools. The Bureau of Agricultural Eonomics (1987) found that estimates of returns to wool growers from their cooperative expenditure on promotion are particularly sensitive to assumptions made about the substitutability of wools which are classified as apparel or non-apparel, on the basis of fibre diameter.

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A major difficulty in estimating demands for graded commodities is the degree of collinearity between prices. This collinearity is natural, resulting from substitution in demand and common sets of determinants of both demand and supply. To overcome the estimation problems associated with collinearity, cross-price relationships were parameterised as a function of fibre diameter. The price relationships were formulated within a demand system derived from a translog cost function. The parametric technique developed may be readily extended to other commodities which are graded on the basis of continuously measured characteristics.

Background information on the fibre diameter composition of Australian wool production and the demand for wool fibres is presented in the next section. A model is then specified and the parameterisation technique is developed. A quantitative analysis and a discussion of the results are presented in the final sections.

Background

Australia supplies about 70 per cent of world exports of apparel wool, defined as wool of 30 microns and finer in diameter. Nearly 83 per cent of Australian wool production falls between 19 and 26 microns in diameter. Finer fibres produce yarns with a more uniform texture and greater strength and softness and this results in an inverse relationship between fibre diameter and price.

Fibre staple length is also an important wool characteristic. Wools are classified into two major types; combing wools, with a staple length of over 37 mm, and carding wools. Combing wools are generally spun on the worsted system, producing yarns with a smooth texture. Carding wools are generally spun on the woollen system, producing coarse-textured yarns. Approximately 85 per cent of Australian wools are classified as combing. The range of wools considered in this analysis (19 to 26 micron combing wools) represent approximately 70 per cent of Australian wool production.

Fibre substitution

Houthakker (1951/52) demonstrated that the utility maximisation framework of consumer choice can be extended to include choices of both quality characteristics and quantities. Consumer demand functions for quality characteristics can be derived which are identical, in form, to an ordinary or compensated quantity demand function. Derived demands for raw fibres will reflect substitution possibilities inherent in consumer's demand for quality characteristics and technical substitution which allows the production of similar quality characteristics from different fibres.

Consumer perceptions of apparel quality may be expressed in terms of characteristics such as comfort, durability, style and warmth. These characteristics are determined, in part, by the physical properties of fabrics. Fabric quality is determined by weaving or knitting methods and the physical characteristics of yarns. Yarn quality is determined by spinning methods and fibre composition. Substitution possibilities between raw fibres will be limited if both consumer demands for apparel quality are price inelastic and the final end-use qualities of apparel are fibre specific.

There is some general evidence to suggest that consumer demand for different end uses of apparel is specific with respect to fibre diameter. Finer wool yarns are generally used to produce woven apparel while coarser wool yarns are used to produce knitwear. Within these general categories, wools of different fibre diameter generally produce fabrics of different finish, handle and weight. For example, finer wools tend to yield a softer textured fabric. Lightweight woven apparel is made from a limited range of fine wools. Thus, the range over which different wools may be regarded as direct substitutes may be limited. Furthermore, complementarity between different apparel end uses may also induce corresponding relationships in wools of different fibre diameter. For example, complementarity between knitted and woven wool apparel may result in a degree of complementarity between fine and coarse apparel wools.

Previous research

Previous research on relative prices within the wool market has mostly provided estimates of the contribution to price of characteristics such as fibre diameter, fibre length and vegetable matter content (Skinner 1965; Bramma, Curran and Gilmore 1985; Simmons 1980). These studies used cross-sectional variation in wool prices to establish that relative prices could be explained in terms of product characteristics. (For an exposition of the theory, see Lancaster 1966.) The single most important characteristic identified in all these studies was fibre diameter. Davidson and Bond (1984) noted, in an analysis of wool prices by fibre diameter, that price differentials between diameter classes have changed substantially over time, in both relative and absolute terms. Consideration of such data suggests that substitution between wools differentiated on the basis of product characteristics is imperfect.

Connolly, MacAulay and Piggott (1987) estimated own-price and cross-price elasticities for six grades of Australian wool. Grades were defined by micron classes which covered the full range of production, including four combing and two carding categories. The estimated own-price elasticities were two to three times larger than those obtained for wool in aggregate (Dewbre, Vlastuin and Ridley 1986; Veldhuizen and Richardson 1983). This indicates that substitution does take place between wool types within the Australian clip. However, because the majority of cross-price relationships were not found to be significant, it appears that direct substitution may be limited by the different physical characteristics of the wool grades defined in the analysis. Alternatively, the lack of significance may have been due to collinearity between the prices of the different wool grades and its effect on the precision of the estimates. Cross-price elasticities between fine combing and fine carding wools, and between medium combing and cross-bred (medium to coarse) carding wools were found to be significant, positive and of similar magnitude.

Reserve price scheme

The Australian Wool Corporation (AWC) stabilises domestic wool prices through the operation of a buffer stock, referred to as the reserve price scheme. The scheme is funded through a grower levy on wool sales. Since September 1974, the AWC has purchased wool at auction according to a schedule of minimum reserve prices, with premiums and discounts for different grades, which is announced at the beginning of each season.[1] Most sales of Corporation stocks have been through private treaty. The operation of a buffer stock has implications for the specification of a model of wool demand.

Wool production is largely determined by climatic conditions and existing sheep inventories. In the absence of a buffer stock scheme, quantities demanded would be predetermined as prices would adjust to equate demand with fixed supplies. Given that the AWC is purchasing or selling stocks however, quantities demanded adjust to the buying and selling prices set by the buffer stock scheme. Over time, different price and quantity regimes are likely to operate and neither prices nor quantities will be fully endogenous or exogenous.

Censored regression models have been proposed to address this problem (see Maddala 1983). However, these employ single-equation techniques and an extension to a system of demand equations is beyond the scope of this paper. The level of AWC stocks for the wool grades under consideration have, in general, varied between seasons. This suggests that quantities demanded are for the most part endogenous and a quantity-dependent specification would be appropriate.

Model Specification

The model selected for the analysis is based on a constant share elasticity cost or price function. The constant share elasticity model, discussed in detail by Jorgenson (1986), offers the simplest formulation of a theoretically consistent factor demand system. Demand relationships are derived from a translog industry cost function under the assumption that the industry exhibits constant returns to scale. To develop a tractable model of the demand for wools of different fibre diameter, two additional separability assumptions were made. First, it was assumed that the demand for fibres is separable from other inputs. Second, it was assumed that the demand for wools of different diameter is separable over some range of Australian wool types.

The translog cost function, under constant returns to scale, may be written:

$$\ln(C) = \alpha_0 + \sum_i \beta_{i0}\ln(p_i) + 1/2\sum_i\sum_j \beta_{ij}\ln(p_i)\ln(p_j)$$

where C is the total cost of wool demanded, α_0 is a constant, β_{ij} is a price coefficient and p_i is the price of wool for the i-th diameter class.

The Hessian of the cost function is symmetric with respect to prices, requiring $\beta_{ij} = \beta_{ji}$. Homogeneity restrictions and the restriction that the cost shares sum to one require:

$$\sum_i \beta_{i0} = 1 \quad \text{and} \quad \sum_j \beta_{ij} = 0$$

[1] The Corporation may also purchase wool at prices above the announced schedule of minimum reserve prices, through a system of flexible reserve prices intended to smooth short-term fluctuations in market prices. However, the great majority of wool purchased by the Corporation has been at minimum reserve prices.

The cost share equation for the i-th micron classes is given by the derivative of the log of total cost with respect to the log of p_i:

$$w_i = \partial \ln(C)/\partial \ln(p_i) = \beta_{i0} + \sum_j \beta_{ij} \ln(p_j) \tag{1}$$

Estimation method

The principal difficulty in estimating a system of demand equations for a group of related commodities is collinearity between prices. When collinearity prevents the direct estimation of cross-price interactions, parametric techniques are commonly employed. Examples of such techniques include the imposition of constant elasticities of substitution and the use of predetermined price indexes. The technique developed here uses physical product characteristics to parameterise price relationships.

Where products are differentiated on the basis of scalar measures of product characteristics, a natural parameterisation is possible. That is, the cross-price relationships can be estimated as a function of the measured characteristics. Consider the parameterisation:

$$\beta_{ij} = \gamma_0 + \gamma_1 d_{ij} \qquad i \neq j \tag{2}$$

where d_{ij} is a metric, measuring the absolute difference in fibre diameter between the mid-points of the i-th and j-th micron classes, and γ_0 and γ_1 are coefficients to be estimated. This parameterisation is symmetric, as $d_{ij} = d_{ji}$.

The derivative of the quantity demanded of the i-th micron class with respect to the price of the j-th micron class, with output held constant, is expressed as a linear function of the measure of the difference in fibre diameter. The cost share for the i-th micron class (equation 1) may be written:

$$w_i = \beta_{i0} + \beta_{ii} \ln(p_i) + \sum_{j \neq i} (\gamma_0 + \gamma_1 d_{ij}) \ln(p_j)$$

or

$$w_i = \beta_{i0} + \beta_{ii} \ln(p_i) + \gamma_0 \sum_{j \neq i} \ln(p_j) + \gamma_1 \sum_{j \neq i} d_{ij} \ln(p_j) \tag{3}$$

This parameterisation is similar in form to distributed lag models, in which time is used as a metric to parameterise the successive lagged effects of a variable which is highly correlated with itself over time. The same effect is achieved here by replacing time with one or more spatial measures of product characteristics. Fibre diameter will be correlated with other factors such as fibre length and strength and to some extent these factors influence substitution and will be reflected in the estimated parameters.

As other input prices are excluded from the model, the homogeneity and adding up restrictions can be used to gain an additional reduction in the number of parameters to be estimated. The restrictions are equivalent, due to symmetry, and may be written:

$$\beta_{ii} = -(n-1)\gamma_0 - \gamma_1 \sum_{j \neq i} d_{ij}$$

where n is the number of micron classes. Substitution of this expression into equation (3) yields the estimating equation:

$$w_i = \beta_{i0} + \gamma_0 \sum_{j \neq i} \ln(p_j/p_i) + \gamma_1 \sum_{j \neq i} d_{ij} \ln(p_j/p_i) + u_i \tag{4}$$

where u_i is a disturbance term.

Given this linear parameterisation, the computation of the regression standard errors for the underlying β coefficients is straightforward. The regression variance of the own-price coefficient is given by:

$$\mathrm{var}(\hat{\beta}_{ii}) = (n-1)^2 \mathrm{var}(\hat{\gamma}_0) + \left(\sum_{j \neq i} d_{ij} \right)^2 \mathrm{var}(\hat{\gamma}_1) + 2(n-1)\left(\sum_{j \neq i} d_{ij} \right) \mathrm{cov}(\hat{\gamma}_0, \hat{\gamma}_1)$$

The regression variance for the cross-price coefficients is given by:

$$\mathrm{var}(\hat{\beta}_{ij}) = \mathrm{var}(\hat{\gamma}_0) + d_{ij}^2 \mathrm{var}(\hat{\gamma}_1) + 2 d_{ij} \mathrm{cov}(\hat{\gamma}_0, \hat{\gamma}_1)$$

Statistical evaluation of value or cost share models

The application of standard regression diagnostics to cost–share equations can yield misleading conclusions with regard to the validity of the underlying demand relationships. For example, if an increase in a commodity price results in an equi-proportional reduction in demand, own prices will be uncorrelated with cost shares. The development of appropriate hypothesis tests of the significance of the demand parameters is straightforward.

The own-price elasticity of demand for the translog model is given by:

$$\varepsilon_{ii} = \left(\beta_{ii} + w_i^2 - w_i\right)/w_i$$

When β_{ii} is zero the own-price elasticity for the i-th good is equal to its cost share minus one. The condition for a zero elasticity forms the correct null hypothesis for testing the significance of the own-price coefficient:

$$H_0\colon\ \beta_{ii} = w_i - w_i^2$$
$$H_a\colon\ \beta_{ii} < w_i - w_i^2$$

where w_i is evaluated at the mean or at some other predetermined level.

The corresponding formula for the cross-price elasticity of the i-th good with respect to the j-th price is, assuming output is held constant:

$$\varepsilon_{ij} = (\beta_{ij} + w_i w_j)/w_i$$

A zero cross-price coefficient implies that the cross-price elasticity is equal to the cost share of the j-th good. The appropriate hypothesis tests are then:

$$H_0\colon\ \beta_{ij} = -w_i w_j$$
$$H_a\colon\ \beta_{ij} \neq -w_i w_j$$

The fact that a well-specified and significant demand relationship may yield a statistically insignificant cost or share equation suggests that goodness of fit diagnostics should be computed with respect to predicted quantities as opposed to shares. Predicted quantities:

$$\hat{q}_i = \hat{w}_i C/p_i$$

yield conditional goodness of fit measures depending on what is assumed regarding the measurement of total cost.

Quantitative analysis

The wool types considered in this study were combing wools from 19 to 26 microns, inclusive. These wools are suitable for the production of worsted wool yarns and represent a reasonably homogeneous range of wool types. Prices used were season average auction prices. Sales to trade were computed as the difference between auction offerings and net changes in AWC stocks. Data on prices and Corporation stocks are published monthly (Australian Wool Corporation 1987*a*) while data on auction offerings are published in annual sales statistics (Australian Wool Corporation 1987*b*). Auction sales have accounted for approximately 83 per cent of total wool sales in Australia since 1978.

Data on the diameter composition of Corporation stocks to the nearest micron were available beginning in the 1976–77 season, limiting the time series to ten yearly observations, from 1977–78 to 1986–87. However, the estimation of parameterised cross-price relationships takes full advantage of both the cross-sectional and time series components of the data (a total of 80 observations). Descriptive statistics for the data are presented in Table 1.

Three alternative measures of the difference in fibre diameter were considered in specifying the parametric cross-price relationship (equation 2): the linear difference in diameter, the square of the difference and the natural logarithm of the difference. These measures correspond to a constant, increasing and decreasing rate of change in the degree of substitutability between diameter classes, respectively.

TABLE 1

Descriptive Statistics for the Data Used in the Analysis

Diameter class	Sample means			Diameter class	Sample means		
	Price	Quantity	Share		Price	Quantity	Share
Micron	$	kt	%	Micron	$	kt	%
19	6·34	242·4	7·3	23	4·67	688·9	15·7
20	5·58	501·8	13·6	24	4·43	435·9	9·5
21	5·22	860·7	21·8	25	4·19	242·3	5·0
22	4·94	984·6	23·6	26	3·94	173·2	3·5

Price correlation matrix

	19m	20m	21m	22m	23m	24m	25m	26m
19m		0·972	0·941	0·912	0·918	0·906	0·890	0·856
20m			0·992	0·976	0·973	0·952	0·932	0·915
21m				0·995	0·991	0·972	0·953	0·946
22m					0·996	0·980	0·964	0·963
23m						0·992	0·980	0·971
24m							0·997	0·985
25m								0·989

The data were pooled across diameter categories and dummy variables were introduced to allow for mean level differences in the category shares. The models were estimated using ordinary least squares.[2] On the basis of goodness of fit the best model was the logarithm of the difference:

$$d_{ij} = \ln |m_i - m_j|$$

where m is the mid-point of a fibre diameter class, measured in microns.[3]

Regression results for the selected model are presented in Table 2. The parameterised regression did not yield significant estimates of the γ coefficients in equation (4). However, the derived coefficients (β) for the demand relationships are, in general, highly significant. The own-price coefficients are negative and significant, at the 5 per cent level, in all categories except the 26 micron class ($i=8$). Cross-price coefficients are positive up to a difference in diameter of 3 microns. The cross-price effects are generally significant, at the 5 per cent level, up to a difference in diameter of 4 microns. Exceptions occur in the coarser micron categories.

Within sample predictions of quantities demanded for each fibre diameter class were computed under the assumption that total costs were exogenous and measured without error. Summary results are presented in Table 3. Two diagnostic tests were performed. A Durbin–Watson statistic was calculated using the predicted and actual quantity values. Errors in each micron class were ordered across time and then pooled. Though not a valid statistic, the value of the Durbin–Watson statistic, 2·04, does not suggest a problem with serial correlation. Reset tests were conducted as an additional test of general model

TABLE 2

Summary of Estimation Results[a]

Coef.	Estimate	Standard error	Coef.	Estimate	Standard error
	Estimated coefficients			Derived cross-price	
α_0	0·051	0·032	β_{ij+1}	0·028	0·019
α_1	−0·033	0·019	β_{ij+2}	0·015	0·011
			β_{ij+3}	0·005	0·006
	Derived own-price		β_{ij-4}	−0·002	0·002
β_{11}	−0·007	0·025	β_{ij+5}	−0·008	0·003
β_{22}	−0·053	0·049	β_{ij+6}	−0·013	0·006
β_{33}	−0·081	0·065	β_{ij+7}	−0·018	0·008
β_{44}	−0·094	0·072			
β_{55}	−0·094	0·072			
β_{66}	−0·081	0·065			
β_{77}	−0·053	0·025			
β_{88}	−0·007				

[a] Constant terms are not reported.

[2] Given the limited time series component of the data, the cross-equation correlation structure cannot be estimated with any degree of precision. Therefore, a generalised least squares approach, such as SUR did not appear warranted.

[3] The differences in the mean square errors for the alternative specifications were not statistically significant at the 10 per cent level.

TABLE 3

Comparison of Actual and Predicted Quantities Demanded

Diameter class	Root mean squared error	
	Level	Percentage
Micron	kt	%
19	2·8	11·9
20	2·3	4·9
21	4·4	4·8
22	4·7	5·4
23	5·9	8·7
24	4·5	10·0
25	4·5	20·3
26	2·9	17·5

specification (Ramsey 1969). Calculated residuals were regressed against squares and cubes of the predicted values. The tests did not yield a significant indication of model misspecification at the 10 per cent level.

Price elasticities (output held constant) were calculated for the system of fibre diameter demand equations using mean price and quantity levels for the sample period. They are presented in Table 4. All the estimated own-price relationships are price elastic. The own-price elasticities exhibit two tendencies. First, they are greater, in absolute terms, in the inner portion of the diameter range. This accords with the fact that there are a greater number of nearby substitutes in the middle of the fibre diameter range. Second, demand tends to become more price elastic as fibre diameter increases. This may indicate a greater degree of substitution among coarser wools, due to less restrictive technical specifications in the production of coarser yarns.

TABLE 4

Estimated Own- and Cross-Price Elasticities for Combing Wools of Different Fibre Diameters

Percentage change in demand	With respect to a percentage change in the price of							
	19m	20m	21m	22m	23m	24m	25m	26m
Micron								
19	−1·02	0·52	0·42	0·31	0·13	−0·01[a]	−0·13[a]	−0·20[a]
20	0·28	−1·23	0·43	0·34	0·20	0·08	−0·01[a]	−0·06[a]
21	0·14	0·26	−1·15	0·36	0·22	0·12	0·04	−0·00[a]
22	0·10	0·20	0·34	−1·16	0·28	0·16	0·07	0·03
23	0·06	0·17	0·31	0·42	−1·44	0·27	0·15	0·07
24	−0·01[a]	0·11	0·27	0·39	0·45	−1·76	0·35	0·19
25	−0·19[a]	−0·02[a]	0·18	0·34	0·45	0·65	−2·00	0·59
26	−0·43[a]	−0·24[a]	−0·01[a]	0·18	0·31	0·52	0·86	−1·17[a]

[a] Estimates were not significant at the 5 per cent level; all remaining estimates were significant at the 5 per cent level (one-tailed test evaluated at sample mean).

The estimated cross-price elasticities decline with the difference in fibre diameter. Generally, the estimated positive cross-price elasticities are statistically significant at the 5 per cent level. Positive elasticities, implying direct pair-wise substitution, are limited to diameter differences of 4 microns or less. None of the negative cross-price elasticities is statistically significant at the 5 per cent level, suggesting that wools with diameter differences greater than 4 microns are not complements.

Conclusions

In this study, a cross-price parameterisation technique was employed to obtain estimates for a system of conditional demand equations for Australian wool by micron class. Price elasticities (output held constant) were obtained from this system. The results suggest that the pair-wise substitution between different fibre diameter categories declines rapidly as the difference in diameter increases, but that within a limited range of fibre diameters the substitution possibilities are substantial. Some part of this decline in substitution may be due to factors such as fibre length and strength which are correlated with fibre diameter. Substitution across the fibre diameter profile may best be characterised by an overlapping shift in the relative demand for wool. For example, an increase in the price of 19 micron wool would induce a substitution of 20 micron wool for 19 micron, 21 micron wool for 20 micron and so forth.

The range over which wools of different diameter may be regarded as direct substitutes was estimated to be around 4 microns. This result is consistent with the hypothesis that different wool types are used to produce yarns for specific end uses. The results are also consistent with those of Connolly *et al.* (1987) who found that direct substitution between broadly defined wool grades was limited. Substitution between end-use types may, for the most part, take place at the margins where there is a technical overlap. Consequently, the demand for end-use types may be considerably less price elastic than for individual micron classes. Factors, such as changes in fashion, which affect consumer demand for wool in particular end uses may have a significant effect on relative wool prices.

The range of direct substitution between wools of different fibre diameters implies that the degree of competition between apparel and non-apparel wool types is very limited. Australia produces wool with an average fibre diameter of about 24 microns, less than 15 per cent being coarser than 26 microns. In contrast, New Zealand, the largest exporter of non-apparel wool, produces wool with an average fibre diameter of around 34 microns, less than 20 per cent being finer than 30 microns. Currently, direct competition between Australia and New Zealand would appear to be limited to the relatively small overlap in their production profiles.

The use of physical characteristics to parameterise cross-price relationships is a useful technique which offers avenues for further research. The technique may be applied to other graded or closely related commodities. One possibility might be the use of energy content and protein to parameterise cross-price relationships between different feed grains.

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