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A SIMULTANEOUS EQUATIONS MODEL WITH ENDOGENOUS SWITCHING: THE DEMAND FOR AUSTRALIAN WOOL

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Until recently the Australian Wool Corporation (AWC) stabilised the price of wool by making sales and purchases of wool under the Minimum Reserve Price (MRP) and Flexible Reserve Price (FRP) schemes. The econometric model presented in this paper describes the simultaneous determination of wool prices and AWC net sales. The model can best be described as a simultaneous equations model with endogenous switching. The parameters of the model are estimated by the method of maximum likelihood. The estimated parameters seem plausible. In particular, the estimated own-price elasticity of demand for wool is close to one.

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1. INTRODUCTION

The Australian Wool Corporation (AWC) administered the Minimum Reserve Price (MRP) and Flexible Reserve Price (FRP) schemes for wool from 1974 until 1991. Both schemes were suspended in February 1991 and were finally abandoned at the commencement of the 1991-92 wool marketing season. In the aftermath of the MRP and FRP schemes the industry found itself with accumulated stocks of wool amounting to approximately 800kt, and financial liabilities in excess of \$2.5 billion. The Australian Wool Realisation Commission (AWRC) is the statutory authority now charged with disposing of the wool stockpile and managing the industry's financial liabilities.

The Australian Bureau of Agricultural and Resource Economics (ABARE) has conducted an extensive program of research into alternative strategies for disposing of the stockpile. One set of models which has been used by ABARE to assess alternative policy options is documented by Beare *et al* (1991). Not surprisingly, Beare *et al* find that the efficiency and equity of the optimal disposal strategy is sensitive to the values of the own-price elasticities of demand and supply. Indeed, Beare *et al* find that relatively small changes in the assumed values of demand and supply elasticities may, for example, lead to a 30% reduction in the optimal time required to liquidate the stockpile.

The own-price elasticity of demand has been an important ingredient into the analysis of many other important wool industry issues. Examples include the assessment of farm and processing research (see Mullen *et al* (1989)) and evaluating the returns from wool promotion expenditures (see BAE (1987)). Unfortunately, the estimation of the own-price elasticity of demand for wool is by no means straightforward. It seems that the range of models which have been used to estimate this parameter is matched only by the range of estimates produced. Dewbre *et al* (1984), for example, report that the elasticity of demand for Australian wool lies in the range -0.6 to -0.8. In contrast, Beare and Meshios (1990) present evidence to suggest that the elasticity of demand ranges from -1.0 to -2.0. In this paper, a nonstandard model of wool demand is used to obtain an elasticity estimate of approximately -1.0.

This paper recognises three features of price determination in the wool industry which are of econometric interest. First, the time series of observations on prices and quantities can be broken into two parts - a period during which the AWC stabilised the price of wool and an earlier period during which it did not. Second, when the AWC was involved in stabilising wool prices, AWC net sales and the price of wool were determined simultaneously. Finally, AWC wool purchases ensured that the price of wool did not fall below a floor price, which means that an endogenous variable (price) was limited in its range. This paper represents these features of wool price determination in the form of a simultaneous equations model with endogenous switching. The focus of the model is not on the censoring of price but on the change (or switch) in the AWC net sales strategy whenever the price of wool fell to its floor.

The plan of the paper is as follows. Section 2 describes the main features of the MRP and FRP schemes and integrates these features into a theoretical model of wool price determination. The associated econometric model is presented in Section 3. The data set is described in Section 4 and the estimation of the model discussed in Section 5. The estimation results are presented in Section 6 and the paper is concluded in Section 7.

2. THE THEORETICAL MODEL

A description of the MRP and FRP schemes and their operation is provided by several authors including Hinchy and Simmons (1983) and ABARE (1990). For modelling purposes it is the MRP and FRP buying and selling strategies which are of particular interest.

The MRP scheme was a type of buffer stock scheme under which the administering authority (the AWC) bought and sold wool in the market place in an attempt to provide a guaranteed minimum price, or floor price, for each type of wool. The scheme differed from the traditional buffer stock scheme insofar as there was no conscious effort to keep market prices within a predetermined band. Rather, the AWC was concerned primarily with keeping the price of each type of wool above its guaranteed minimum. For the most part, the guaranteed minimum prices for each type of wool were nondecreasing, remained fixed for an entire wool marketing season, and were announced just prior to the season in which they were intended to prevail.

The FRP scheme was a somewhat more discretionary scheme which allowed wool to be purchased at specific auction centres if bids were low relative to the rest of the market, or if the entire market was affected by some short-term disturbance (Hinchy and Simmons, 1983, p 45). Flexible reserve prices appear to have been set as often as the AWC deemed necessary but, unfortunately, were not published.

Wool which had been accumulated under the MRP and FRP schemes was sold on the open market using a set of rules which, again, were not publicly known. Sometimes wool from the AWC stockpile was re-offered at brokers auctions or at auctions organised by the AWC itself. Alternatively, accumulated stocks of wool were sold by private treaty. The private treaty pricing policy of the AWC was not publicly known but it is believed that if wool was held in Australian stockpiles then it was held on offer at a premium to the recent auction price. If wool was held in foreign stockpiles then the offer price was also adjusted for transport costs. Some confirmation of this pricing policy was provided by Asimus (1979, p 4):

"the disposal policy we have followed in recent weeks is much on the lines of the policy we have followed throughout this year: selling at prices equivalent to auction prices while the

market is rising but seeking a slight premium when the market is stable. The objective generally has been to steady the rate of rise in prices and to maintain stable situations."

Representing these buying and selling practices in the form of an economic model is reasonably straightforward. For a start, the general form of the relationship between the price of wool and total wool supply is given by:

$$(1) \quad p = h(x, q+s)\xi$$

where h is a function, p denotes the price of wool, q denotes wool production, s denotes AWC net sales, $x=(x_1 \dots x_n)'$ is an $(n \times 1)$ vector of exogenous variables and ξ is a random variable representing demand side sources of price instability. The random variable ξ is introduced multiplicatively for analytical convenience. The variables p and s are endogenous. It is assumed that the level of wool production q is exogenous on the grounds that producers must have made their input decisions before output prices and AWC net sales were known.

It is assumed that the function h can be inverted with respect to $q+s$ so that:

$$(2) \quad q+s = h^{-1}(x, p\xi^{-1})$$

where the notation h^{-1} denotes the inverse function with respect to $q+s$. Under this assumption, the level of AWC net sales which would have ensured a floor price of f is obviously given by:

$$(3) \quad s = h^{-1}(x, f\xi^{-1}) - q$$

Indeed, it is supposed that the AWC entered the market and made net sales of wool according to the rule:

$$(4) \quad s = h^{-1}(x, f\xi^{-1}) - q \quad \text{if } p \leq f$$

$$(4') \quad = g(z, p, f, q, v) \quad \text{otherwise}$$

In equations (4) and (4') g is a function, $z=(z_1 \dots z_m)'$ is an $(m \times 1)$ vector of exogenous variables, f represents an average of the MRP floor prices for different types of wool, and v is a random variable which, amongst other things, accounts for random variations in the amount of stockpiled wool the AWC offered for sale.

Equation (4) specifies the amount of wool the AWC was forced to purchase under the MRP scheme in order to stop the average price of wool p from falling below the average floor price f . It should be noted

that p equalled f only when the prices of all different types of wool were equal to their respective floor prices.

Equation (4') accounts for three types of behaviour by the AWC. First, it accounts for AWC purchases of wool under the FRP scheme. To be more precise, the vector of exogenous variables z and the random variable v account for the short-term disturbances which resulted in FRP purchases taking place.

Second, equation (4') accounts for AWC purchases of wool under the MRP scheme when the prices of some types of wool were still greater than their floor. In this case the average price of wool was greater than the average floor price ($p > f$). As the prices of more types of wool fell to their floor prices, p approached f and AWC purchases under the MRP scheme increased. Clearly the function g is an increasing function of the difference between p and f .

Finally, equation (4') accounts for sales of wool from AWC stockpiles. The basis upon which wool buyers decided to purchase at auction or from the AWC stockpile is somewhat uncertain, and the random variable v can account for this uncertainty. The vector of exogenous variables z is also a determinant of the amount of wool placed on offer.

3. THE ECONOMETRIC MODEL

In order to estimate the parameters of the model it is necessary to be more explicit about the form of the functions h and g . There are a number of possibilities here, but for analytical convenience it is assumed that:

$$(5) \quad h(x, q+s) = \beta_0 x_1^{\beta_1} \dots x_n^{\beta_n} (q+s)^{1/\epsilon}$$

and

$$(6) \quad g(z, p, f, q, v) = \alpha_0 z_1^{\alpha_1} \dots z_m^{\alpha_m} p^{\delta} f^{\delta} q v - q$$

where $\beta_0, \dots, \beta_n, \alpha_0, \dots, \alpha_m, \delta$ and ϵ are parameters to be estimated, ϵ being the own-price elasticity of demand.

Equation (5) is the double-log specification popularised by many applied econometricians. Equation (6) is essentially a double-log specification which combines with equation (5) in a manner which is analytically convenient. Following the discussion in Section 2, it is worth noting that in equation (6) the wool price p and the floor price f appear in the form of the ratio p/f , with exponent δ . It is also worth noting that equation (6) can be written in the form:

$$(6) \quad g(z, p, f, q, v) = q(\alpha_0 z_1^{\alpha_1} \dots z_m^{\alpha_m} p^{\delta} f^{\delta} v^{\delta} - 1)$$

which implies that AWC net sales are simply a stochastic proportion of wool production q .

Under these assumptions the econometric model can be written:

$$(7) \quad \ln p = \beta_0^* + \beta_1 \ln x_1 + \dots + \beta_n \ln x_n + (1/e) \ln(q+s) + \ln \xi$$

$$(8) \quad \ln(q+s) = \omega_0 + \omega_1 \ln x_1 + \dots + \omega_n \ln x_n + e \ln f + \ln \varepsilon \quad \text{if } \ln p \leq \ln f$$

$$(8') \quad = \alpha_0^* + \alpha_1 \ln z_1 + \dots + \alpha_m \ln z_m + \delta \ln p - \delta \ln f + \ln q + \ln v \quad \text{otherwise}$$

where $\beta_0^* = \ln \beta_0$

$$\alpha_0^* = \ln \alpha_0$$

$$\omega_0 = e \beta_0^*$$

$$\omega_j = e \beta_j \quad j=1, \dots, n$$

and $\ln \varepsilon = -e \ln \xi$

The data used to estimate the model have important implications for the form of the likelihood function and are described below.

4. DATA

In this paper it is assumed that the vector x contains three variables and the vector z contains one variable (ie $n=3$, $m=1$). The variables are as follows:

$x_{1t} = e^t$ is a time trend,

x_{2t} = United States GNP in constant 1982 dollars,

x_{3t} = the Australia/US exchange rate,

z_{1t} = the sum of AWC opening stocks and brokers unsold stocks.

where t has been introduced to indicate time.

The x_{it} variables are more or less standard inclusions in demand functions for wool (see for example, Fisher (1983)). The time trend is included to capture the effects of developments in both the synthetic and natural fibre markets. United States GNP is included as an indicator of levels of economic activity in countries which consume large quantities of wool. Fisher (1983) used an index of industrial output in

OECD countries to account for this influence, but this particular index is unavailable for some time periods. The Australia/US exchange rate is included in its own right because the general equilibrium consequences of exchange rate changes may mean that price and exchange rate movements have quite different effects on wool demand (Chambers and Just, 1979, p 253).

AWC opening stocks plus brokers unsold stocks is one of several variables which have been included in other studies of AWC purchases or sales. For example, Carland (1981) attempted to model AWC gross sales using AWC opening stocks, the rate of economic activity in Japan, synthetic fibre prices, world consumer prices, world interest rates and the wool stocks-to-consumption ratios of mills in major wool consuming countries. However, Carland found that coefficients on all variables other than AWC stocks were incorrectly signed and not significantly different from zero. For this reason, and in order to conserve a small number of degrees of freedom, the number of z_{it} variables in the function g is restricted to one.

The data set consists of 39 observations covering the period 1949-50 to 1987-88 inclusive. The AWC used the MRP and FRP schemes to stabilise the price of wool in the last 15 time periods. Importantly, the average price of wool never coincided with the average floor price, which implies that at no time were the prices of *all* different types of wool equal to their respective floor prices. The consequences for estimation of the model will become apparent below.

Finally, the data set was constructed as follows:

- The Minimum Reserve Price Indicator was used as a measure of the MRP average floor price. Indicator prices were provided on a greasy basis by ABARE for all but one time period. For that time period the Minimum Reserve Price Indicator was converted from clean to greasy equivalent by dividing by the Clean Market Indicator and then multiplying by the annual average price of greasy wool. These indicators and prices were provided by ABARE.
- The financial year average real price of greasy wool was used as a measure of the price of wool, and the total financial year production of wool was used as a measure of wool output. These data, together with the Australia/US exchange rate and the opening value of (AWC and brokers unsold) stocks, were also supplied by ABARE.
- Data on AWC FRP and MRP purchases and sales were provided by the AWC in farm bale equivalents. These data were converted to '000 kg greasy in line with the composition of AWC closing stocks.
- United States Gross National Product in constant 1982 dollars was obtained from *Survey of Current Business* (various issues).

5. ESTIMATION

The model can best be described as a simultaneous equations model with endogenous switching - the value of one endogenous variable acts as a switch which governs the regime under which the value of the second endogenous variable is determined. Models of this type bear a great deal of similarity to censored regression or *tobit* models which are discussed at length by Amemiya (1974). In the standard tobit nomenclature the model is written:

$$(9) \quad y_{1t} = \gamma_1 y_{2t} + x_{1t}' \beta_1 + u_{1t}$$

$$(10) \quad y_{2t}^* = x_{2t}' \beta_2 + u_{2t}$$

$$(11) \quad y_{3t}^* = \gamma_3 y_{1t} + x_{3t}' \beta_3 + u_{3t}$$

$$(12) \quad y_{2t} = y_{2t}^* \quad \text{if } y_{1t} \leq k_t$$

$$(12') \quad = y_{3t}^* \quad \text{otherwise}$$

$$\text{where } y_{1t} = \ln p_t$$

$$y_{2t} = \ln(q_t + s_t)$$

$$k_t = \ln f_t$$

$$x_{1t}' = (1 \quad \ln x_{1t} \quad \dots \quad \ln x_{nt})$$

$$x_{2t}' = (1 \quad \ln x_{1t} \quad \dots \quad \ln x_{nt} \quad \ln f_t)$$

$$x_{3t}' = (1 \quad \ln z_{1t} \quad \dots \quad \ln z_{nt} \quad \ln f_t \quad \ln q_t)$$

$$u_{1t} = \ln \xi_t$$

$$u_{2t} = \ln \varepsilon_t$$

$$u_{3t} = \ln v_t$$

$$\gamma_1 = 1/e$$

$$\gamma_3 = \delta$$

and the definitions of the remaining coefficients are obvious. In the early time periods the model consists of a single equation only (ie equation (9) with y_{2t} redefined as $\ln q_t$). In the last 15 time periods the model consists of equations (9) to (12'). Because there are no time periods in which $y_{1t} \leq k_t$ (ie there are no time periods in which equation (12) applies) the likelihood function is broken into only two parts:

$$(13) \quad L = \prod_{t \in S_0} f_1(y_{1t}) \prod_{t \in S_1} f_{13}(y_{1t}, y_{3t}^*)$$

where f_1 is the probability density function of y_{1t} ,

f_{13} is the joint probability density function of y_{1t} and y_{3t}^*

S_0 is the set of time periods for which the model consists of a single equation only.
and S_1 is the remaining set of time periods, for which $y_{1t} > k_t$

The density functions f_1 and f_{13} are derived under the assumption that ξ_t and v_t are independent lognormal random variables. From a theoretical perspective, the lognormality assumption ensures that wool prices are non-negative. From a practical viewpoint, the lognormality assumption implies that the u_{it} ($i=1, \dots, 3$) are normally distributed. The u_{it} are assumed to have zero means and finite variances σ_i^2 .

Together these assumptions imply that:

$$(14) \quad g_1(u_{1t}) = \frac{1}{\sigma_1 \sqrt{2\pi}} \exp\left(-\frac{1}{2\sigma_1^2} u_{1t}^2\right)$$

and

$$(15) \quad g_{13}(u_{1t}, u_{3t}) = \frac{1}{2\pi\sigma_1\sigma_3} \exp\left[-\frac{1}{2\sigma_1^2} u_{1t}^2 - \frac{1}{2\sigma_3^2} u_{3t}^2\right]$$

where g_1 is the probability density function of u_{1t} , and g_{13} is the joint probability density function of u_{1t} and u_{3t} . The density functions f_1 and f_{13} are derived from the density functions g_1 and g_{13} . Specifically:

$$(16) \quad f_1(y_{1t}) = g_1(y_{1t} - \gamma_1 y_{2t} - x_{1t}'\beta_1) J_1$$

and

$$(17) \quad f_{13}(y_{1t}, y_{3t}^*) = g_{13}(y_{1t} - \gamma_1 y_{2t} - x_{1t}'\beta_1, y_{3t}^* - \gamma_3 y_{1t} + x_{3t}'\beta_3) J_{13}$$

where J_1 is the Jacobian of the transformation from u_{1t} to y_{1t} , and J_{13} is the Jacobian of the transformation from (u_{1t}, u_{3t}) to (y_{1t}, y_{3t}^*) . The Jacobian J_1 is unity while the Jacobian J_{13} is given by:

$$(18) \quad J_{13}(y_{1t}, y_{3t}^*) = -s_t/q_t - \gamma_1 \gamma_3$$

Equations (13) to (18) together imply that the likelihood function is given by:

$$(19) \quad L = \prod_{t \in S_0} \frac{1}{\sigma_1 \sqrt{2\pi}} \exp\left(-\frac{1}{2\sigma_1^2} (y_{1t} - \gamma_1 y_{2t} - x_{1t}'\beta_1)^2\right) \\ \times \prod_{t \in S_1} \frac{(-s_t/q_t - \gamma_1 \gamma_3)}{2\pi\sigma_1\sigma_3} \exp\left[-\frac{1}{2\sigma_1^2} (y_{1t} - \gamma_1 y_{2t} - x_{1t}'\beta_1)^2 - \frac{1}{2\sigma_3^2} (y_{2t} - \gamma_3 y_{1t} + x_{3t}'\beta_3)^2\right]$$

The negative of this likelihood function was minimised iteratively. The iterations were controlled by a monitor program known as NLMON. NLMON is an adaption of a program originally written by Wales (1976). At each iteration the negative of the likelihood function was minimised using the POWEL and FMIN algorithms.

6. RESULTS

Maximum likelihood (ML) estimates of the parameters are reported in Table 1 below. For purposes of comparison, Table 1 also contains a set of estimates obtained by applying Ordinary Least Squares (OLS) to equations (7) and (8') separately. These are the estimates which are obtained when simultaneity is ignored. Importantly, failure to account for simultaneity means that these estimates are biased and inconsistent.

All the ML estimates are correctly signed although some are not statistically different from zero at the usual levels of significance ($\hat{\beta}_1$, $\hat{\beta}_2$ and $\hat{\beta}_3$). In terms of magnitudes, some of the more interesting results are:

- (i) The estimated coefficient of the time trend is slightly less than zero which, not surprisingly, implies that developments in synthetic and natural fibre markets lead to a gradual reduction in the demand for wool.
- (ii) The own-price elasticity of demand for Australian wool is estimated to be $e = -1/1.030 = -0.97$. Interestingly, this estimate is well outside the interval $[-0.6, -0.8]$ reported by Dewbre *et al* (1984), and just outside the interval $[-1.0, -2.0]$ reported by Beare and Meshios (1990).
- (iii) The demand for wool appears to be quite sensitive to changes in levels of economic activity. Specifically, the elasticity which measures the change in the demand for wool in response to a change in US GNP is estimated to be 1.55 (inverting the estimated inverse demand function means that the coefficient estimate of 1.598 should be divided by 1.030 to yield an elasticity estimate of 1.55).
- (iv) The demand response to a change in the exchange rate appears to be inelastic. The elasticity which measures the change in the demand for wool in response to a change in the exchange rate is estimated to be -0.71 ($= -0.733/1.030$).

Table 1: Coefficient Estimates*

Equation	Coefficient	Variable	ML		OLS	
			Estimate	Estimated Standard Error	Estimate	Estimated Standard Error
(7)	β_0^*	Constant	1.863	23.6593	11.671	10.362
	β_1	Time trend	-0.077	0.1133	0.016	0.0502
	β_2	US GNP	1.598	3.6186	0.535	1.6122
	β_3	Exchange Rate	-0.733	0.5868	-1.408	0.3983
	1/e	Wool Prod ⁿ + AWC Sales	-1.030	0.4032	-1.666	0.3795
(8')	α_0^*	Constant	-.447	0.1703	-0.293	0.0109
	α_1	AWC Opening Stocks	0.092	0.0346	0.002	0.0037
	δ	Wool/Floor Price Ratio	0.033	0.0196	-0.006	0.0105

* ML estimation yielded R^2 values of 0.73 and 0.75 for equations (7) and (8') respectively. Each R^2 value was calculated as one minus the ratio of the sample variance of the dependent variable to the sample variance of the residuals. Note that because the residuals do not necessarily sum to zero the range of R^2 is $[-\infty, 1]$.

- (v) Both slope coefficients in the stockholding function are positive, which means that decreases in the price of wool and decreases in AWC stockholdings of wool both lead to an increase in AWC purchases.

Failure to account for simultaneity appears to have three important consequences for the coefficient estimates. First, the estimated own-price elasticity of demand falls from -0.97 to -0.6, which is at the lower end of the range reported by Dewbre *et al* (1984). Second, the estimated coefficient on the time trend in the inverse demand schedule ($\hat{\beta}_1$) and the estimated coefficient on the wool/floor price ratio in the stockholding function ($\hat{\delta}$) become incorrectly signed. Finally, the estimated slope coefficients in the stockholding function become insignificantly different from zero at the usual levels of significance.

7. CONCLUSION

It is evident from the agricultural economics literature that the choice of econometric model may have a large bearing on the estimated magnitude of the own-price elasticity of wool demand. This paper has used a simultaneous equations model with endogenous switching to obtain an estimate of approximately -1.0. This value contrasts with an estimate of approximately -0.6 which is obtained using an identical model in which simultaneity is ignored. Other models have yielded estimates as high as -2.0.

The sensitivity of own-price elasticity estimates to the choice of econometric model is of more than just passing interest. The results of policy simulations are often determined by the assumed values of this and other parameters. Beare *et al* (1991), for example, have found that an increase in the value of the own-price elasticity of demand from -1.0 to -1.2 would lead to an increase in wool stockpile sales revenues and a reduction in the optimal stockpile disposal horizon under strategies designed to maximise either net stockpile sales revenues or industry wealth. It is comforting to note that Beare *et al* assessed optimal stockpile disposal strategies using a baseline demand elasticity of -1.0, which coincides with the estimate obtained in this study, and is somewhere near the middle of the range of estimates reported elsewhere in the literature.

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