SOME ESTIMATES OF SUPPLY AND INVENTORY RESPONSE FUNCTIONS FOR THE CATTLE AND SHEEP SECTOR OF NEW SOUTH WALES

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Econometric procedures are employed in an analysis of N.S.W. cattle and sheep producers' decision-making regarding the annual supplies of beef, veal, lamb, mutton and wool, and annual changes in the inventory levels of beef cows, dairy cows, steers, adult sheep and ewes mated to British breed rams. A simultaneous equation model containing fourteen stochastic equations is specified and estimated using annual data for the period 1953–4 to 1970–1. A set of derived reduced form functions are employed in a study of some dynamic behavioural relationships in the cattle and sheep sector. The estimated model is used to analyse some effects on prices, quantities and inventory levels of the imposition of a (10 cent per kg) tax on beef exports.

1 INTRODUCTION

The environment in which decisions influencing performance of the N.S.W. livestock sector are made is characterized by fluctuating price and pastoral conditions. These fluctuations, many of which are erratic, may lead to significant changes in the quantities of livestock products produced, in the prices received for these products and in the numbers of breeding animals retained for future production. Indirectly these factors influence returns to the livestock industries, the demand for abattoir facilities, the supplies of products for export, and so forth. This study attempts to add to knowledge about the responses of cattle and sheep producers to changes in economic and pastoral conditions.

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Several articles have reported attempts to quantify the more important factors affecting the supplies of livestock products in Australia. The most comprehensive analysis was carried out by a team at Monash University headed by Professor Gruen.[1] A six-sector model based on the concept of a constant elasticity of transformation production function was used to study the annual Australian supply of beef, wool, lamb, wheat, coarse grains and dairy products for the period 1947–8 to 1964–5. The study reported here differs in several respects from the Monash study. First, this study is restricted to one state, N.S.W., whereas the Monash study is an aggregate study of Australian production. Second, less restrictive assumptions in terms of homogeneity and symmetry constraints on the estimates are employed.[2] Finally, in this study we consider inventory response as well as supply response, with the beginning livestock inventory providing a measure of output capacity for the supply functions, whereas the Monash study employed lagged output as a proxy for output capacity.[3]

Several studies have examined the supplies of one or two livestock products but have a different orientation to the study reported here. These include studies on wool supply by Dahlberg [8], Witherall [36], Duloy and Watson [10] (in connection with their study of wheat supply), the Bureau of Agricultural Economics [2], and Davidson [9] (in connection with his study of beef supply). Studies of the beef sector have been made by Gutman [21], Patterson [26], White [35], Davidson [9], and Throsby [31].

The study reported here is concerned with the simultaneous determination of the average annual prices and the annual supplies of N.S.W. beef, veal, lamb, mutton and wool, and the annual inventory levels of beef cows, dairy cows, steers, adult sheep and ewes intended to be mated to British breed rams. Producer decision making models under conditions of imperfect information in which the cattle and sheep industries are regarded as competitive investment activities for the utilization of pasture and other resources underly the model specified. Using annual time series data for the period 1953–4 to 1970–1 econometric procedures are employed to obtain estimates of the parameters of the livestock supply functions and of the livestock inventory functions.

The development of the study falls into five sections. In section two the structural model is specified. Estimates of the parameters of the stochastic structural equations are reported in section three. Section four provides an interpretation and evaluation of these estimated

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[1] Some of the results of this work are reported in Gruen, *et al.* [19] and Powell and Gruen [28]. The study has been reviewed by Guise [20] and by Watson, *et al.* [34].

[2] This was one of the issues raised by Watson, *et al.*, [34]. The subsequent discussion in the same journal illicited by the Watson *et al.* comments is of interest.

[3] In the case of beef the Monash team treated the number of breeding beef cows as a predetermined proxy variable for capacity.

functions. In the fourth section the reduced form model is derived and discussed. The final section considers some applications of the estimated model, including an analysis of the effects of a tax on beef exports.

2 MODEL SPECIFICATION

In this section a set of functions describing the important relationships and causal variables influencing the prices, outputs, and inventories of cattle and sheep are specified. The final form of the relations is based on economic models describing producer decision-making behaviour and the available data.

2.1 MODEL OF LIVESTOCK PRODUCERS' DECISION MAKING

An investment decision model is used to describe the decision-making processes in which N.S.W. producers as an aggregate make decisions on the quantities of livestock products to send to market and on changes in the inventory levels of livestock in response to economic and pastoral conditions. The investment model stems in part from the various studies of manufacturing investment initiated by Jorgenson [22] and others. Court [7] has employed a similar model in a study of New Zealand sheep production.

Livestock Decision Making Environment

Four characteristics of the environment in which livestock producers' decisions are made are to be emphasized. First, the dual nature of beef cattle and sheep are recognized. At any decision period these animals may either be slaughtered for the current production of meat or be retained for future production levels. The latter includes retention for breeding purposes,[4] for the production of other products such as wool, and for slaughter in future periods. Thus, in livestock decision-making producers must consider the future as well as the immediate effects of their decisions. This places a dynamic component in the investment decision model.

Second, cattle and sheep activities are assumed to be competing activities for the utilization of limited pasture forage resources.[5] Thus. important variables influencing livestock producers' decisions will be relative profitability measures for the different livestock activities and measures of the available supplies of pasture forage.

[4] The importance of gestation periods should be emphasized with respect to breeding purposes.

[5] A less restrictive assumption of competitive relationships at and around current livestock mix levels will suffice for the empirical section of this study. Davidson [9] argues the case for a competitive relationship between cattle and sheep.

Third, at this stage it is assumed that individual producers regard market prices as independent of their activities. This assumption is imposed only in specifying the structural relations; in terms of the complete model some of the price variables are specified as jointly dependent variables.

Fourth, producers do not have perfect knowledge of prices or of pasture supplies, particularly the levels of these variables in future periods. It will be assumed that producers make decisions on the basis of probabalistic assessments of these variables.

A Sketch of the Livestock Investment Decision Model

An investment decision model involves the choice of a time sequence of decision variables which maximize an objective function subject to a set of constraints. The details of the investment model used in this study are given in appendix A. At this stage some results of the model as they relate to producer decisions regarding the annual supply of livestock products and changes in the inventory levels of cattle and sheep are presented in summary form.

In general terms aggregate values for the t-th period decision variables, annual quantity of product i supplied (Q_{it}) and ending inventory of livestock type j (K_{jt}), can be expressed in terms of:

(i) the opening livestock inventory variables, K_{t-1};

(ii) expected current and future output prices, $E(P_t, P_{t+1}, \ldots)$, where E is the expectation operator;

(iii) the expected variability of these prices, $Var(P_t, P_{t+1}, \ldots)$, where Var is the variance operator;

(iv) the level of pasture resources, PR; and

(v) the prices of purchased inputs,[6] C.

It may be noted that the structural relations for the supply of livestock products and for the inventory levels of livestock have a recursive structure. The current (say t) period supplies of livestock products are in part a function of the opening inventories of livestock (K_{t-1}). Of course, the opening inventory levels provide a measure of capacity. The same factors influencing current supplies influence also the closing inventories of livestock (K_t). These final inventory levels are the opening inventory levels in the next decision period (period $t + 1$).

[6] In the remainder of the paper we omit any consideration of this variable. This is done as a simplifying approximation. Data on this variable, particularly in terms of relative costs of purchased inputs to the different activities, is scant and these costs are of lesser importance than output prices in sheep and cattle profit calculations.

Decisions in any period are influenced not only by producers' information about prices in the current period but also by their information about prices in future decision periods. At the cost of a simplifying assumption of stationary price expectations the sequence of expected output prices and the variance of these prices can be reduced to a single variable (Gould [17]), i.e. the sequence $E(P_t, P_{t+1}, \ldots)$ can be condensed to $E(P_t)$. Stationary expectations assume that producers as an aggregate do not anticipate cyclical or secular price movements.[7]

The price variability variables allow for the effects of producers having risk averting (or preference) utility functions. The approach adopted here is a natural extension of the models of micro decision-making reported in the Bayesian decision theory literature.

The pasture resources variable, *PR*, essentially specifies the particular production possibility surface which constrains producers' decisions.

In summary, our investment decision model of aggregate livestock producers' decision-making behaviour suggests structural relations which describe the supply of livestock products and the inventory of livestock in terms of the opening inventory of livestock, expected output prices of the different competitive livestock products, a measure of expected variability of these prices, and a measure of pasture availability.

2.2 DATA AVAILABILITY

Data on inventory levels of the different types of livestock are reported as at 31st March. Cattle are distinguished on the basis of primary use for milk production and other (beef) production. The only basis for the annual classification of sheep by principal end use, i.e. between wool and prime lamb production, is by intention to mate ewes to particular breed of ram. The intended mating of ewes to British breed rams will be used as an indicator, albeit a crude one,[8] of the inventory of lamb production capacity.

Data on the quantities of livestock products produced will be specified on a financial year basis. For the purposes of this study some limitations in the available data on quantities were encountered. The data does not distinguish between calves slaughtered from dairy and beef herds and it does not distinguish between lambs according to type of lamb, e.g. between second cross, first cross and merino.

Output prices in this study are specified as average prices for financial years. Since the structural equations will involve expected prices and the anticipated variability of prices, $E(P_t)$ and $Var(P_t)$, for which there is no data it is necessary to express these variables in terms of available data.

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[7] No evidence, one way or the other, regarding this hypothesis was found.

[8] For a further discussion of this assumption *see* Bureau of Agricultural Economics [3].

Our understanding of how producers form expectations about prices is at an elementary stage.[9] Typically, econometricians have specified expected prices, $E(P_t)$, in terms of distributed lag functions, i.e.

$$E(P_t) = \sum_{i=0}^{\infty} w_i P_{t-i}$$

where the w_i's are weights.[10] In this study a number of weighting schemes, including the arithmetic lag structure, the geometric lag structure and the extrapolative expectations model were tried. In evaluating the suitability of the alternative models the explanatory powers of estimated regression equations (based on the coefficient of multiple determination) and the signs and statistical significance (based on estimated 't' values) of the regression coefficients using the different models were considered. On this basis the three-period arithmetic lag structure gave satisfactory results. In the subsequent sections of the study the following crude model of the formation of expected prices is assumed:

(1) $E(P_i) = P_i^* = \cdot 5P_{i-1} + \cdot 33P_{i-2} + \cdot 17P_{i-3}$.

With respect to producers' information about the anticipated variability of future prices it is assumed that:

(2) $Var(P_i) = VP_i = Range(P_i, P_{i-1}, P_{i-2})$

The crude and arbitrary nature of this specification should be noted.[11]

No direct measure of available pasture resources is available. In the empirical part of the study two variables are used as a proxy measure of available pasture forage: the area of improved pastures (IP) and a weather index variable (W). While livestock graze on native and improved pastures (and also on crop stubble and fallow), the area of improved pastures can be interpreted as a measure of increased carrying capacity relative to the pasture land it replaces. Also, inspection of time series data suggests that the rate of expansion of improved pasture acreage has been sensitive to the area of wheat grown.[12] An index of rainfall provides a crude measure of the productivity of pasture land.

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[9] For a survey of recent developments in this area the reader is referred to Nerlove [24]. Some empirical work is reported by Turnovsky [33].

[10] For a review of distributed lag functions *see* Griliches [18].

[11] A more appropriate measure would be a moving variance estimate. The selection of the three prices is comparable to the three prices used in specifying the expected price variable (1).

[12] From 1950 until 1965, the area of improved pastures steadily increased up to 4·48 million hectares. In the following 4 years wheat acreage expanded rapidly while the area of improved pastures declined to 4·16 million hectares in 1969. Since the introduction of wheat quotas the area of improved pastures has been increasing.

This index is based on a set of rainfall maps showing annual (calendar) rainfall in deciles. After some experimentation with different weighting schemes the rainfall index variable is specified as:[13]

$$(3)\quad W = \begin{cases} 1 \text{ for decile ranges 9 and 10 (e.g. 1969)} \\ 0 \text{ for decile ranges 4 through 8 (e.g. 1970, 1971)} \\ -1 \text{ for decile range 3 (e.g. 1957)} \\ -2 \text{ for decile range 2 (e.g. 1965)} \\ -3 \text{ for decile range 1 (e.g. 1944)} \end{cases}$$

The index indicates that pasture production is greatly reduced in low rainfall years but is not increased to the same extent in above average rainfall years. Relative to the quantity variables and the ending inventory variables the weather index spans the prior calendar year; this assumption places some lag effect on the influence of weather on pasture availability.

2.3 SPECIFICATION OF ECONOMIC MODEL

This subsection presents a listing and brief description of the relationships describing the average annual prices and the annual quantities supplied of cattle and sheep products, and the closing levels of cattle and sheep inventories for N.S.W. To simplify the notation the time subscript "t" is omitted, and the additive random error term is omitted from the stochastic functions. Detailed definitions of the variables, the data sources, and the explicit classification of variables as endogenous or as exogenous are given in appendix B.

Farm Prices

(4) $P_B = f(P^e{}_B, Q_B, Q_V, Q_L, Q_M, Y)$

(5) $P_L = f(P^e{}_L, Q_B, Q_V, Q_L, Q_M, Y)$

(6) $P_M = f(P^e{}_M, P_W, Q_B, Q_V, Q_L, Q_M, Y)$

(7) P_W predetermined.

(8) P_D predetermined.

As a simplifying approximation it is assumed that wool prices (P_W) and the price of manufacturing milk (P_D) are independent of the levels of these commodities produced in N.S.W. In view of the importance of international trade factors, more so for wool than for butter, this assumption seems to be a reasonable one. Also, butter prices are influenced by institutional arrangements to an important extent.

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[13] Generally, the weighting scheme used gave better statistical estimates in terms of explanatory power of the estimated regression equations and statistical significance of the coefficient on W than other schemes tried. Other weighting schemes tried included the symmetrical weighting system used by Duncan [11].

The price functions for beef (P_B), lamb (P_L) and mutton[14] (P_M) are based on demand functions at the farm level. They take into consideration international trade demands via (exogenous) export prices ($P^e{}_i$), domestic demand shift factors via income (Y), and supplies of the red meats (Q_i). These relations are similar to the auction price relations employed by Marceau [23].

Cattle Activities

At the inventory level the cattle sector is segregated into beef cows (subscript B), north coast dairy cows (subscript $D{\cdot}N$), other dairy cows (subscript $D.O$) and steers (subscript S). Calves may be allocated as (i) beef herd replacements, (ii) dairy herd replacements, (iii) calf slaughter for veal production, or (iv) be retained as steers for further feeding. Cows and steers may be sent for slaughter or retained for breeding or for further feeding.

(9) $K_{D\cdot N} = f(P^*_B, P^*_D, W, T)$

(10) $K_{D\cdot O}$ predetermined.

(11) $K_D = K_{D\cdot N} + K_{D\cdot O}$

(12) $K_B = f(P^*_B, P^*_D, P^*_W, P^*_L, VP_B, IP, W)$

(13) $CLS = f(K_{B-1}, K_{D-1}, P^*_B, W)$

(14) $K_S = f(K_{B-1}, K_{D-1}, CLS, P^*_B)$

(15) $Q_V = f(CLS, K_B/K_D)$

(16) $Q_B = f(K_{B-1}, K_{D-1}, K_{S-1}, P^*_B, P^*_D, P^*_W, P^*_L, VP_B, W)$

The closing inventory of North Coast dairy cows ($K_{D\cdot N}$) is influenced by the expected relative price of manufacturing milk production (P^*_D) to that of beef production (P^*_B), seasonal conditions (W) and a time variable (T). The latter is a crude proxy reflecting the growing age structure of the dairy farm population and political steps in recent years to reduce the production of manufacturing milk in this area (e.g. the dairy industry reconstruction scheme).

Dairy cows in other areas of the State ($K_{D\cdot O}$) are used primarily for fluid milk production and the number of these animals required is largely determined by population and technology.

The closing inventory of beef cows (K_B) is influenced by the expected relative profitability of beef production (P^*_B) to that of manufacturing milk production (P^*_D) and of sheep production (P^*_W and P^*_L), the anticipated variability of beef prices (VP_B), the area of improved pastures (IP) and seasonal conditions (W).

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[14] The mutton price variable P_M is the price of cull sheep. Cull sheep represent a joint product consisting of mutton and wool (*via* skin value).

The number of calves slaughtered (*CLS*) is expressed as a function of the number of calves born, where K_{B-1} and K_{D-1} are proxy variables for the numbers of beef type calves and dairy type calves, respectively, the expected profitability of beef production (P^*_B) and seasonal conditions (W).

The relation describing the closing inventory of steers (K_S) is a crude proxy function. Steers form the residuals of the calf drop (where K_{B-1} and K_{D-1} are proxy variables for this unknown number) which are not slaughtered as calves (*CLS*) or retained as herd replacements. At higher expected beef prices (P^*_B) it might be anticipated that steers would be sold to make fodder available for expansion of the breeding herd.

Veal production (Q_V) is specified as a function of the number of calves slaughtered and of the types of calves slaughtered, e.g., bobby calves or vealers, where the relative importance of the different types of calves is crudely measured by the proxy variable K_B/K_D.

The quantity of beef produced (Q_B) is influenced by the opening inventories of cattle (K_{B-1}, K_{D-1} and K_{S-1}), the expected relative profitability of beef production (P^*_B and VP_B) to that of competing forms of livestock production (P^*_W, P^*_L and P^*_D) and seasonal conditions (W).

Sheep Activities

Distinction is made between all adult sheep (K_{AS}) and a subset of this inventory, the number of ewes intended to be mated to British breed rams (K_L). Adult sheep may be slaughtered for mutton or retained for wool production and flock expansion. It is assumed that most slaughter lambs derive from crosses with British breed rams.

(17) $K_{AS} = f(P^*_W, P^*_L, P^*_B, VP_W, P_M, IP, W)$

(18) $K_L = f(P^*_L, P^*_W, P^*_B, VP_L, IP, W)$

(19) $Q_W = f(K_{AS-1}, P^*_W, P^*_L, P^*_B, VP_W, P_M, W, T)$

(20) $Q_M = f(K_{AS-1}, P^*_W, P^*_L, P^*_B, VP_W, P_M, W)$

(21) $Q_L = f(K_{L-1}, P^*_L, P^*_W, P^*_B, VP_L, W)$

The closing stock of adult sheep (K_{AS}) is specified as a function of the expected profitability of wool and lamb production (P^*_W and P^*_L) to that of beef production (P^*_B), the opportunity cost of sheep slaughter (P_M), the anticipated variability of wool prices (VP_W), the area of improved pastures (IP), and seasonal conditions (W). Note that in this and the other sheep activity functions the farm price of cull sheep (P_M) is assumed to be known by producers whereas producers are assumed to have imperfect knowledge about the (future) prices of wool, lamb and beef.

The closing inventory of potential lamb mothers (K_L) is influenced by the expected relative profitability of lamb production (P^*_L) to that of wool and beef production (P^*_W and P^*_B), the anticipated variability of lamb prices (VP_L), the area of improved pastures (IP) and seasonal conditions (W).

Annual wool production (Q_W) is assumed to be a function of the beginning inventory of adult sheep (K_{AS-1}) with adjustments to this number as influenced by the expected relative profitability of sheep production (P^*_W, P^*_L and VP_W) to that of beef production (P^*_B) and sheep slaughter (P_M). Also, wool production is influenced by seasonal conditions (W) and a technology index (T) to reflect secular rises in wool cut per sheep. The latter observation was noted by Powell and Gruen [27].

The supply of mutton (Q_M) is assumed to be influenced by similar variables with the exception that the price variables have a reverse effect, i.e., increased sheep numbers and wool production come at the expense of mutton production and *vice versa.*

Annual lamb production (Q_L) is influenced by the opening inventory of potential lamb mothers (K_{L-1}), the expected relative profitability of lamb production (P^*_L and VP_L) to that of wool and beef production (P^*_W and P^*_B) and seasonal conditions (W).

3 ESTIMATION OF STRUCTURAL RELATIONS

This section reports some estimates of the parameters of the stochastic equations (4), (5), (6), (9), (12), (13), (14), (15), (16), (17), (18), (19), (20) and (21) of the economic model formulated in the previous section. Before proceeding several additional operating assumptions, and an appropriate estimator, are required.

3.1 SOME OPERATING ASSUMPTIONS

To place the structural equations in a form suitable for estimation the algebraic form of the equations and some properties of the error terms must be specified.

Two algebraic forms of the stochastic functions are investigated. In the first form, which we do not report here, all variables are treated additively in a linear function. In the second form expected prices are specified in the form of relative prices and all other variables are specified additively.[15] At the cost of specifying a homogeneity of degree zero assumption the latter procedure saves some degrees of freedom, reduces some sources of multicollinearity, and generally improves the efficiency (i.e., lower variance estimates) of the parameter estimates.

[15] It should be noted that these functional forms are only approximations. Care is required in using the estimated relations to extrapolate beyond the sample space.

An additive error term is included in each stochastic equation. It is assumed that each error term has zero expectation and is time independent. It is likely that error terms in different equations have non-zero covariances. This arises because of the interdependence of supply decisions and inventory decisions (via the investment decision model) for particular types of livestock and because of the interdependence of decision making for the different types of livestock.

3.2 CHOICE OF THE ESTIMATOR

The parameters of the stochastic equations are estimated by two stage least squares. This choice recognizes that all of the stochastic equations contain two or more endogenous variables.[16] Given our assumptions about the error terms the estimates will have the property of consistency, but they will not be asymptotically efficient relative to three stage least squares estimates. The latter estimator was not chosen because it was thought that approximations employed in specifying some of the relations[17] could have undesirable effects on the estimates of parameters in other equations.[18]

Eighteen observations for the sample period 1953–54 to 1970–71 are used in estimating the regression coefficients. Because of the small sample problem, i.e. because the number of observations (18) is less than the number of predetermined variables (22), as shown by Swamy and Holmes [29] and Fisher and Wadycki [13] the two-stage least squares estimator reduces to the ordinary least squares estimator.

3.3 EMPIRICAL RESULTS

In this section selected estimates of the coefficients of the stochastic regression equations are reported and evaluated. Some of the variables included in the specification of the economic model of section two have been omitted provided (a) their sign is inconsistent with our prior reasoning, (b) omission of the variable has a minor effect on the estimates of the coefficients on other variables, and (c) the ratio of the mean coefficient estimate to its standard error is small (generally less than one). For those estimated equations in which variables have been omitted the more complete estimated equations are shown in

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[16] Also, all equations are overidentified.

[17] In particular, data limitations influenced the specified relations for the closing inventory of steers (14), calf slaughter (13), veal production (15) and the supply of lamb (21), and approximate algebraic forms of the relations are used.

[18] For details of these arguments *see* Goldberger [16].

appendix C. Estimated standard errors are reported in parentheses below their respective mean estimates.[19] The coefficient of multiple determination adjusted for degrees of freedom, R^2, the estimate of the standard error parameter, S, and the Durbin-Watson statistic, d, are shown to facilitate evaluation of the estimated equations.

Farm Prices

$$(22)\quad P_L = \underset{(11{\cdot}42)}{41{\cdot}82} + \underset{({\cdot}1820)}{{\cdot}4807}\, P^e{}_L - \underset{({\cdot}4235)}{1{\cdot}0995}\, kg(Q_L)$$

$$- \underset{({\cdot}1012)}{{\cdot}1256}\, kg(Q_M + Q_V + Q_B) + \underset{({\cdot}0064)}{{\cdot}0108}\, Y$$

$$R^2 = {\cdot}71 \qquad S = 3{\cdot}02 \qquad d = 1{\cdot}69$$

$$(23)\quad P_B = \underset{(8{\cdot}53)}{28{\cdot}73} + \underset{({\cdot}3192)}{{\cdot}9500}\, P^e{}_B - \underset{({\cdot}1192)}{{\cdot}3144}\, kg\,(Q_V + Q_B)$$

$$- \underset{({\cdot}2019)}{{\cdot}2121}\, kg\,(Q_M + Q_L) + \underset{({\cdot}0099)}{{\cdot}0015}\, Y$$

$$R^2 = {\cdot}92 \qquad S = 3{\cdot}08 \qquad d = 1{\cdot}51$$

$$(24)\quad P_M = \underset{(5{\cdot}95)}{-11{\cdot}86} + \underset{({\cdot}1739)}{{\cdot}9017}\, P^e{}_M + \underset{({\cdot}0258)}{{\cdot}1059}\, P_W$$

$$R^2 = {\cdot}62 \qquad S = 1{\cdot}89 \qquad d = 1{\cdot}50$$

In all cases $kg\,(\cdot)$ is the kilograms per capita operator.

The estimated functions for the farm prices of lamb (22) and beef (23) are reasonable in terms of signs of coefficients and statistical properties of the estimates, although the coefficient on income in the beef relation is unstable. They suggest that farm prices are positively related to export price and personal disposable income, and negatively related to per capita supplies of red meats with the more important influence being own supplies.

In the preferred estimated equation for the farm price of cull sheep (24) the farm price of cull sheep is positively related to the export price of mutton and the farm price of wool. Inclusion of the meat supply variables gave unsatisfactory results in terms of the signs and statistical significance of the estimated coefficients.[20]

[19] These estimates are approximate only since they are based on the concept of a large sample.

[20] For details *see* appendix C.

Cattle Activities

$$\text{(25)}\quad \underset{}{K_{D\cdot N}} = \underset{(45\cdot3)}{773\cdot8} - \underset{(138\cdot9)}{256\cdot9}\, P^*_B/P^*_D - \underset{(3\cdot60)}{10\cdot86}\, T$$

$$R^2 = \cdot90 \qquad S = 27\cdot7 \qquad d = \cdot81$$

$$\text{(26)}\quad K_B = \underset{(332\cdot02)}{83\cdot78} + \underset{(446)}{1686}\, P^*_B/(\cdot8\, P^*_W + \cdot1\, P^*_L + \cdot1\, P^*_D)$$

$$-\underset{(12\cdot58)}{32\cdot28}\, VP_B + \underset{(116\cdot4)}{284\cdot7}\, IP + \underset{(63\cdot91)}{23\cdot08}\, W$$

$$R^2 = \cdot86 \qquad S = 183 \qquad d = 1\cdot90$$

$$\text{(27)}\quad K_S = \underset{(93\cdot0)}{709\cdot1} + \underset{(\cdot0218)}{\cdot1218}\, (K_{B-1} + K_{D-1}) - \underset{(\cdot0883)}{\cdot3670}\, CLS$$

$$-\underset{(1\cdot079)}{5\cdot475}\, P^*_B$$

$$R^2 = \cdot81 \qquad S = 23\cdot3 \qquad d = 2\cdot23$$

$$\text{(28)}\quad Q_B = -\underset{(42\cdot8)}{138\cdot7} + \underset{(\cdot0157)}{\cdot1304}\, (K_{B-1} + K_{D-1} + K_{S-1}) + \underset{(4\cdot735)}{9\cdot459}\, W$$

$$-\underset{(27\cdot7)}{128\cdot4}\, P^*_B/(\cdot8\, P^*_W + \cdot1\, P^*_L + \cdot1\, P^*_D) + \underset{(\cdot936)}{\cdot954}\, VP_B$$

$$R^2 = \cdot85 \qquad S = 12\cdot9 \qquad d = 2\cdot41$$

$$\text{(29)}\quad CLS = \underset{(127\cdot6)}{100\cdot2} + \underset{(\cdot0635)}{\cdot4204}\, (K_{B-1} + K_{D-1}) - \underset{(42\cdot7)}{333\cdot2}\, (K_B/K_D)_{-1}$$

$$-\underset{(8\cdot38)}{18\cdot12}\, W - \underset{(1\cdot124)}{4\cdot253}\, P^*_B$$

$$R^2 = \cdot95 \qquad S = 27\cdot0 \qquad d = 2\cdot02$$

$$\text{(30)}\quad Q_V = -\underset{(3\cdot564)}{4\cdot625} + \underset{(\cdot0042)}{\cdot0384}\, CLS + \underset{(\cdot952)}{2\cdot746}\, (K_B/K_D)_{-1}$$

$$R^2 = \cdot90 \qquad S = 1\cdot17 \qquad d = 1\cdot34$$

The estimated relation for the closing stock of North Coast dairy cows (25) indicates a decline in dairy cow numbers with increased relative profitability of beef to manufacturing milk production and with the passage of time (which is a proxy for the social and institutional factors inducing a decline in the dairy industry). Inclusion of the variable for seasonal conditions made no significant contribution to the regression function. Attempts to remove the autocorrelation in (25) using the assumption of a first order markov process were not successful. Thus, while the mean estimates in (25) have satisfactory properties the standard error estimates should be treated with caution.

The closing stock of breeding beef cows (26) is positively related to the expected relative profitability of beef production to that of sheep and manufacturing milk production,[21] the area of improved pastures and favourable seasonal conditions, although the latter variable is not significantly different from zero in the usual statistical sense. The negative coefficient on the beef price variability variable VP_B is consistent with an hypothesis that cattle producers as an aggregate are risk averters.

The stock of steers (27) is positively related to the number of calves born (where K_{B-1} and K_{D-1} are proxy variables), and is negatively related to the number of calves slaughtered and the expected profitability of beef production. The latter form of causation suggests some substitution of an increased breeding herd for steers during periods of higher prices under conditions of limited pasture supplies.

The annual quantity of beef production (28) is positively related to the opening inventory of cattle (beef cows, dairy cows and steers) and favourable seasonal conditions, and is negatively related to the expected relative profitability of beef to sheep and dairy production. No evidence was found to support an hypothesis that the slaughter rate varies between beef cows, dairy cows or steers.[22] However, the slaughter rate is sensitive to expected relative prices of cattle and sheep production.[23] The estimated beef cow closing inventory equation (26) and the estimated beef supply equation (28) indicate that when beef prices rise relative to prices of competing livestock activities, producers expand the breeding herd and part of this expansion comes at the cost of current production.

The relations for calf slaughter (29) and for the supply of veal (30) are consistent with prior expectations. While the calf slaughter rate is higher among dairy type calves these calves are marketed at lighter weights than beef-type calves. Favourable seasonal conditions and optimistic beef price expectations reduce the calf slaughter rate indicating that producers retain calves for further feeding or for breeding purposes under these conditions.

Generally, the cattle equations are consistent with prior notions, most of the explanatory variables are highly significant and they explain a significant portion of the variation of the dependent variables.

---

[21] The weights specified on prices of competing products were chosen arbitrarily with some reference to the relative importance, in terms of gross returns, of the different products. This procedure has been followed in subsequent equations.

[22] Initial attempts at estimating the beef supply equation with K_{B-1}, K_{D-1} and K_{S-1} as separate variables provided unsatisfactory estimates. When the equation was estimated with $(K_{B-1} + K_{D-1} + K_{S-1})$ as a variable and with additional variables such as $K_{B-1}/(K_{B-1} + K_{D-1} + K_{S-1})$ the additional variables were not significantly different from zero (at about the 30 per cent level). During the sample period steers (K_S) were a fairly constant 20 per cent of the term $(K_B + K_D + K_S)$. The statistical results suggest about constant cull rates for beef cows and dairy cows over the sample period.

[23] Such a result is contrary to the assumption employed by White [35] in his model.

Sheep Activities

$$
\begin{aligned}
(31)\quad K_{AS} &= \underset{(3{\cdot}01)}{45{\cdot}52} - \underset{(3{\cdot}62)}{11{\cdot}99}\, P^*_B/({\cdot}9\, P^*_W + {\cdot}1\, P^*_L) - \underset{({\cdot}1249)}{{\cdot}4517}\, P_M \\
&\quad + \underset{({\cdot}4191)}{{\cdot}8024}\, W + \underset{({\cdot}9637)}{5{\cdot}8416}\, IP \\
&\quad R^2 = {\cdot}72 \qquad S = 1{\cdot}43 \qquad d = 1{\cdot}53
\end{aligned}
$$

$$
\begin{aligned}
(32)\quad K_L &= \underset{(2{\cdot}97)}{-15{\cdot}66} + \underset{(6{\cdot}17)}{17{\cdot}75}\, P^*_L/({\cdot}8\, P^*_W + {\cdot}2\, P^*_B) + \underset{({\cdot}0615)}{{\cdot}1328}\, VP_L \\
&\quad + \underset{({\cdot}2413)}{{\cdot}5167}\, W + \underset{({\cdot}596)}{4{\cdot}030}\, IP \\
&\quad R^2 = {\cdot}85 \qquad S = {\cdot}73 \qquad d = 1{\cdot}93
\end{aligned}
$$

$$
\begin{aligned}
(33)\quad Q_W &= \underset{(46{\cdot}45)}{-26{\cdot}70} + \underset{({\cdot}903)}{6{\cdot}754}\, K_{AS-1} + \underset{({\cdot}722)}{2{\cdot}528}\, T + \underset{(2{\cdot}94)}{26{\cdot}38}\, W \\
&\quad - \underset{(107{\cdot}4)}{296{\cdot}9}\, P_M/({\cdot}9\, P^*_W + {\cdot}1\, P^*_L) \\
&\quad R^2 = {\cdot}90 \qquad S = 9{\cdot}38 \qquad d = 1{\cdot}54
\end{aligned}
$$

$$
\begin{aligned}
(34)\quad Q_M &= \underset{(35{\cdot}17)}{-80{\cdot}13} + \underset{(13{\cdot}37)}{56{\cdot}74}\, P^*_B/({\cdot}9\, P^*_W + {\cdot}1\, P^*_L) \\
&\quad + \underset{({\cdot}717)}{2{\cdot}914}\, K_{AS-1} + \underset{(2{\cdot}430)}{3{\cdot}068}\, W \\
&\quad R^2 = {\cdot}79 \qquad S = 7{\cdot}68 \qquad d = 1{\cdot}32
\end{aligned}
$$

$$
\begin{aligned}
(35)\quad Q_L &= \underset{(23{\cdot}25)}{83{\cdot}92} + \underset{(1{\cdot}024)}{9{\cdot}631}\, K_{L-1} - \underset{({\cdot}389)}{1{\cdot}767}\, P^*_L - \underset{({\cdot}654)}{1{\cdot}061}\, VP_L \\
&\quad R^2 = {\cdot}89 \qquad S = 7{\cdot}51 \qquad d = 1{\cdot}52
\end{aligned}
$$

The closing inventory of adult sheep (31) is positively related to the expected relative profitability of sheep (both lamb and wool) to beef production, seasonal conditions and the area of improved pastures, and is negatively related to the price of cull sheep. The variable measuring wool price variability, VP_W, was omitted from the preferred relation because of its limited explanatory properties.[24]

The closing inventory of ewes intended to be mated to British breed rams (a proxy measure of lamb production capacity) (32) is positively related to the expected relative profitability of lamb to wool and beef production, seasonal conditions, the area of improved pastures and the lamb price variability variable. The latter causal relationship suggests that lamb producers are risk preferers—an unexpected result, but one which is consistent with the negative coefficient on the lamb price variability variable in the lamb supply equation (35).

[21] This was done also for the wool supply and mutton supply equations.

The annual production of wool (33) is positively related to the opening inventory of sheep, the technology surrogate time and favourable seasonal conditions, and is negatively related to the relative price of cull sheep to the expected profitability of wool and lamb production. The latter causal relationship is consistent with the closing sheep inventory equation (31) in that the inventory of sheep (and hence wool production) is positively related to the expected profitability of sheep and is negatively related to the price of cull sheep.

In the preferred mutton supply function the estimated annual supply of mutton (34) is positively related to the opening inventory of sheep and seasonal conditions, and is negatively related to the expected relative profitablility of sheep (wool and lamb) to beef production. The latter causal relationship indicates, as expected, that the sheep slaughter rate is sensitive to the relative expected profitability of sheep to cattle activities. The positive coefficient on the seasonal index variable, W, suggests that higher sheep slaughter weights and reduced mortality rates in good seasons outweight the effects on the supply of mutton of inducements to producers to retain additional sheep (as specified in (31)). The farm price of cull sheep has been deleted as an explanatory variable from the preferred mutton supply equation. When this variable was included in the equation its estimated coefficient was negative and its estimated standard error was relatively large.[25] The negative sign was unexpected, both in terms of *a priori* reasoning and in relation to the estimated relations for the closing inventory of sheep (31) and for wool supply (33).[26] Considerable caution in the interpretation and use of equation (34) should be exercised.

The supply of lambs (34) is positively related to the inventory of lamb mothers, and negatively related to the expected profitability of lamb production. The latter association implies that as lamb profitability rises, producers retain first cross ewe lambs for breeding purposes rather than sell them for slaughter. A similar relationship has been noted by Witherell [36, p. 146].

With the exception of the equation for mutton supply, the estimated sheep activity equations are considered satisfactory on both *a priori* and statistical grounds.

4 SOME INTERPRETATIONS OF THE ESTIMATED STRUCTURAL MODEL

In this section the estimated functions of the previous section are used to derive some farm price, supply and inventory elasticities. These estimates are compared with other estimates which have been reported in the literature.

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[25] For details, *see* appendix C.

[26] In a more comprehensive study the use of a mixed estimator which forces consistency of coefficient estimates between the equations for sheep inventory, wool supply and mutton supply could be attempted.

From the farm price equations which are based on a derived demand model we can obtain estimates of the farm price-export price elasticities and the demand price flexibility coefficients. These coefficients, which are reported in table 1, are derived for average sample values over the decade 1960–70. The farm price-export price elasticities for beef and mutton are approximately unity and for lamb about a half. The latter low figure may be explained by the fact that relative to beef and mutton only a small proportion of N.S.W. lamb is exported and most of this takes place during the October-December quarter.

TABLE 1

Estimated Demand Price Flexibilities and Farm Price-Export Price Elasticities for Beef, Lamb and Mutton in N.S.W.

Farm price	Demand price flexibility			Farm price-export price elasticity
	Beef and Veal	Lamb	Mutton	
Beef	−·27	−·10	−·09	1·01
Lamb	−·21	−·86	−·10	·51
Mutton ..	†	†	†	1·16

† Specified to be zero.

The price flexibility coefficients in table 1 approximate the auction price flexibilities reported by Marceau [23] in his quarterly model of N.S.W. meat demand for the period 1951–63. These estimates suggest that the farm demand for beef and lamb is elastic,[27] particularly for beef, and, of course the farm demand for mutton and wool have been specified as infinitely elastic. Because of the importance of export demand for these products these results are as expected.

In table 2 estimates of the inventory response elasticities with respect to farm prices and the area of improved pastures are reported. The price elasticities, e_{kji}, are intermediate period (3 year) price elasticities calculated as

$$(36)\quad e_{kji} = \frac{\partial K_j}{\partial P^*_i}\frac{\overline{P}_i}{\overline{K}_j}$$

where, as before, K_j is the closing inventory of animal type j, $P^*_i(= \cdot 5\, P_i + \cdot 33\, P_{i-1} + \cdot 17\, P_{i-2})$ as defined in (1) is the expected average annual farm price of product i, $\overline{P}_i$ and $\overline{K}_j$ are average 1960–70 values, and the partial derivatives are taken from the appropriate closing inventory function of section three.[28] The inventory response elasticity with respect to the area of improved pastures is calculated analogously.

[27] The elasticity estimate is approximately the inverse of the flexibility estimate.

[28] The derivatives are calculated for average 1960–70 levels of the price variables.

TABLE 2

Estimated Intermediate Inventory Response Elasticities for Beef Cows, Adult Sheep, Ewes Mated to British Breed Rams and North Coast Dairy Cows with Respect to Prices and the Area of Improved Pastures

Inventory variable	Prices†					Area of improved pastures
	Wool	Beef	Lamb	Mutton	Dairy	
Beef cows	−·409	·469	−·021	‡	−·039	1·373
Adult sheep	·115	−·116	·005	−·176	‡	·462
Ewes mated to British breed rams	−·682	−·008	·771	‡	‡	2·382
North coast dairy cows	‡	−·330	‡	‡	·330	‡

† Estimated according to (36) in the text.

‡ Specified to be zero.

The signs of the inventory response elasticities reported in table 2 follow from the discussion of the estimated closing inventory functions of section three above. The number of beef cows increases with the price of beef but declines with the prices of wool, lamb and butter; the magnitudes of the own beef price elasticity and the cross wool price elasticity are about ·5 and −·4, respectively. The number of adult sheep increases with the prices of wool (elasticity of about ·1) and lamb and declines with rises in the prices of beef (elasticity of about −·1) and cull sheep (elasticity of about −·2). The number of ewes intended to be mated to British breed rams is primarily influenced by the lamb price (elasticity of about ·8) and the wool price (elasticity of about −·7). All the price elasticities are less than unity.

Changes in the area of improved pastures have a marked influence on the rate of expansion of the beef, wool and lamb industries with estimated inventory expansion elasticities of 1·4, ·5 and 2·4, respectively (table 2). As has been noted elsewhere, for example, in the B.A.E. study of wool supply [2], the area of improved pastures may be also a proxy for a number of other management and technology advances.

Upon making the assumption that all the farm price variables are predetermined[29] and substituting out the opening inventory variables in the supply relations, the time response patterns of livestock supplies to price changes can be assessed. Formally, for the beef supply equation, (29) is substituted into (27) to eliminate *CLS*, then this equation and equations (25) and (26) are substituted into (28) to eliminate K_{S-1}, $K_{D\cdot N-1}$ and K_{B-1}, respectively. For the lamb supply equation, (32) is substituted into (35) to eliminate K_{L-1}. In the mutton supply equation and the wool supply equation, (31) is substituted into

[29] In section five below this assumption is relaxed.

(34) and (33), respectively, to eliminate K_{AS-1}. In addition, the expected price variables P^* ($= \cdot 5\,P + \cdot 33\,P_{-1} + \cdot 17\,P_{-2}$) are expanded in terms of their time sequence. The following product supply equations, which we denote as partial reduced form equations, express quantity supplied, Q_i, in terms of current and lagged farm price variables,[30] P_i, P_{i-1}, P_{i-2} and P_{i-3}.

$$
\begin{aligned}
(37)\quad Q_B = {} & -66{\cdot}05\,P_B/(\cdot 8\,P_W + \cdot 1\,P_L + \cdot 1\,P_D) \\
& + 69{\cdot}77\,(P_B/(\cdot 8\,P_W + \cdot 1\,P_L + \cdot 1\,P_D)_{-1} - 17{\cdot}25\,(P_B/P_D)_{-1} \\
& - \cdot 268\,P_{B-1} \\
& + 52{\cdot}35\,(P_B/(\cdot 8\,P_W + \cdot 1\,P_L + \cdot 1\,P_D)_{-2} - 11{\cdot}40\,(P_B/P_D)_{-2} \\
& - \cdot 174\,P_{B-2} \\
& + 38{\cdot}54\,(P_B/(\cdot 8\,P_W + \cdot 1\,P_L + \cdot 1\,P_D)_{-3} - 5{\cdot}87\,(P_B/P_D)_{-3} \\
& - \cdot 09\,P_{B-3} + \text{other terms,}
\end{aligned}
$$

$$
\begin{aligned}
(38)\quad Q_L = {} & -\cdot 883\,P_L \\
& - \cdot 583\,P_{L-1} + 85{\cdot}48\,(P_L/(\cdot 8\,P_W + \cdot 2\,P_B))_{-1} \\
& - \cdot 300\,P_{L-2} + 56{\cdot}41\,(P_L/(\cdot 8\,P_W + \cdot 2\,P_B))_{-2} \\
& + 29{\cdot}06\,(P_L/(\cdot 8\,P_W + \cdot 2\,P_B))_{-3} + \text{other terms,}
\end{aligned}
$$

$$
\begin{aligned}
(39)\quad Q_M = {} & 28{\cdot}37\,P_B/(\cdot 9\,P_W + \cdot 1\,P_L) \\
& + 1{\cdot}25\,(P_B/(\cdot 9\,P_W + \cdot 1\,P_L)_{-1} - 1{\cdot}316\,P_{m-1} \\
& - 1{\cdot}885\,(P_B/(\cdot 9\,P_W + \cdot 1\,P_L))_{-2} \\
& - 5{\cdot}94\,(P_B/(\cdot 9\,P_W + \cdot 1\,P_L))_{-3} + \text{other terms, and}
\end{aligned}
$$

$$
\begin{aligned}
(40)\quad Q_W = {} & -296\,P_m/(\cdot 45\,P_W + \cdot 29\,P_{W-1} + \cdot 15\,P_{W-2} + \cdot 05\,P_L \\
& + \cdot 03\,P_{L-1} + \cdot 02\,P_{L-2}) \\
& - 3{\cdot}05\,P_{m-1} - 40{\cdot}5\,(P_B/(\cdot 9\,P_W + \cdot 1\,P_L))_{-1} \\
& - 26{\cdot}72\,(P_B/(\cdot 9\,P_W + \cdot 1\,P_L))_{-2} \\
& - 13{\cdot}77\,(P_B/(\cdot 9\,P_W + \cdot 1\,P_L))_{-3} + \text{other terms.}
\end{aligned}
$$

The partial reduced form equations (37) through (40) indicate complex temporal relationships between quantity supplied and farm prices. For the meats the direction of effect of a price change may alter over time. For example, in the beef supply equation (37) a rise in the price of beef relative to wool and lamb prices reduces beef supplies in the current year as the breeding herd is expanded, but in successive years the expanded herd facilities increased beef production. A similar relationship holds for lamb. In the case of mutton, increases in wool and lamb prices relative to beef prices reduce the supply of mutton in the current and following year, but in subsequent years the increased flock facilitated by the price rise results in increased mutton supplies. Increases in wool supplies are associated with favourable wool and lamb prices in all years while higher cull sheep prices reduce wool supplies in the current and following year and higher beef prices reduce wool supplies after a lag of one year.

[30] To simplify the exercise the price variability variables VP_B and VP_W are included with W, IP and the constant in the component "other terms".

The negative current period response of beef and lamb supplies to increases in their own prices is in conflict with the positive first period supply responses reported by Powell and Gruen [28]. This conflict can be traced to the flexibility of the underlying investment decision model used in this study. By separating out the supply and inventory decision functions, the investment model allows but does not require a change in the direction of effect of a price change on quantity supplied over time. On the other hand, the Powell and Gruen model enforces a one direction effect.

Estimates of intermediate supply elasticities for beef, lamb, mutton and wool reported in table 3 illustrate the competitive relationships between the supplies of livestock products and farm prices. The intermediate (four year) elasticities, e_{ij}, are calculated as

$$(41)\ e_{ij} = \left[\sum_{r=0}^{3} \partial Q_i / \partial P_{j-r}\right] \overline{P}_j / \overline{Q}_i$$

where Q_i is the annual quantity of product i supplied, P_j is the average annual farm price of product j, $\overline{P}_i$ and $\overline{Q}_j$ are the average values of these variables over the decade 1960–70, r is an index of lagged years, and the partial derivatives are from equations (37) through (40).[31]

TABLE 3

Estimated Four Year Supply Elasticities for Wool, Beef, Lamb and Mutton

Quantity	Price†				
	Wool	Beef	Lamb	Mutton	Dairy
Wool	·369	−·137	·015	−·416	‡
Beef	−·189	·110	−·010	‡	·078
Lamb	−·700	−·085	·032	‡	‡
Mutton	−·102	·107	−·005	−·259	‡

† Calculated according to (41) in the text.

‡ Specified to be zero.

With the exception of the direct price elasticity for mutton the signs of the supply elasticity estimates in table 3 are consistent with prior notions. The negative direct price elasticity of supply for mutton is a result of the unsatisfactory estimated mutton supply equation (34); namely, that the estimated function does not include the price of cull sheep as a positive explanatory variable. The estimates suggest important

[31] The derivatives are calculated for average 1960–70 levels of the price variables.

competitive relationships, e.g. between beef and wool and between mutton and wool, and some complementary relationships, e.g. between dairy and beef. In the case of wool and lamb, higher lamb prices increase wool production (by inducing an increase in sheep numbers) while higher wool prices reduce lamb production (by inducing a reduction in the number of ewes mated to British breed rams).

The supply elasticity estimates of table 3 compare reasonably well with other estimates reported in the literature. The direct price elasticity for wool is comparable to the five year elasticity of ·335 reported by Powell and Gruen [28], the long run estimates of ·125 to ·276 by Witherall [36] and the B.A.E. estimate of ·160 [2]. None of these studies reported significant cross price elasticities between beef and sheep, however Davidson [9] in his normative analysis reported important competitive relationships between these enterprises. The estimated lamb direct price supply elasticity of ·032 in table 3 is low relative to the 5-year elasticity estimate of 1·385 reported by Powell and Gruen [28]. The direct beef supply elasticity estimate of ·110 also is low relative to the one year elasticity estimate of ·160 reported by Powell and Gruen [28]—they did not estimate a longer run beef supply elasticity. In this study significant competitive cross-price elasticities between beef and wool and between beef and lamb were obtained whereas Powell and Gruen [28] reported zero cross-price elasticities between these outputs. It is likely that these cross-price elasticities account for some of the discrepancy between the Powell and Gruen [28] estimates of the direct price elasticities for lamb and beef and those reported in table 3. Also, in this study the area of improved pastures was assumed to be a predetermined variable independent of livestock prices, an assumption not imposed by Powell and Gruen [28]. If, as expected,[32] lagged livestock prices positively influence the area of improved pastures the intermediate elasticities of table 3 underestimate the long run supply elasticities.

The estimated equations suggest that the variability of farm prices have some explanatory power in describing the aggregate supply and inventory response functions of N.S.W. sheep and cattle producers. For the crude measure of anticipated price variability used in this study[33] and assuming quadratic utility functions (either intrinsically or as an approximation)[34] the estimated equations indicate that beef producers as an aggregate are risk averters, that lamb producers as an aggregate are risk preferers, and that wool producers as an aggregate are indifferent to price uncertainty. These results may be compared to the micro-oriented studies by Officer *et al* [25] and Francisco and Anderson [14] who reported that most but not all of the graziers they studied exhibited risk aversion behaviour.

---

[32] Duncan's [12] study would support this hypothesis.

[33] Further work will include the analysis of alternative measures of producers' information about the anticipated variability of prices.

[34] The studies by Officer *et al.* [25] and Francisco and Anderson [14] indicate that quadratic functions in the variable profits provide reasonable approximations.

Seasonal conditions, as measured by the index of annual rainfall specified in (3), have important influences on the supplies of livestock products and on the rate of growth of the inventory levels of cattle and sheep. In table 4 mean estimates of these effects are shown for a below average rainfall year (rainfall decile three) and a severe drought year (rainfall decile one) relative to average rainfall years (rainfall deciles four through seven). While poor seasonal conditions have no influence on the annual level of lamb supplies they have a substantial depressing effect on the annual supply of wool and lesser, but still important depressing effects on the annual supplies of beef and mutton. Inventory levels of cattle and sheep, particularly intended matings of ewes to British breed rams, are reduced during periods of poor seasonal conditions.

TABLE 4

Estimated Current Year Effect of a Below Average Rainfall Year and a Severe Drought Year on Annual Supplies of Beef, Wool, Lamb and Mutton and on Inventory Levels of Cattle and Sheep

	Below average rainfall*		Severe drought†	
	No.	Per cent‡	No.	Per cent‡
Effect on Supply of:				
Beef (1 000 t)	−9·5	−4·0	−28·5	−11·9
Wool (million kg) ..	−26·4	−7·8	−79·2	−23·3
Lamb (1 000 t)	§	§	§	§
Mutton (1 000 t) ..	−3·0	−3·0	−9·0	−9·0
Effect on Inventory of:				
Beef cows (1,000) ..	−23·1	−1·3	−69·3	−3·9
Adult sheep (million) ..	−0·8	−1·5	−2·4	−4·6
Ewes mated to British breed rams (million)	−0·5	−4·5	−1·5	−13·6

* Annual rainfall in third decile range.

† Annual rainfall in first decile range.

‡ Estimated in terms of average 1960–70 values of the variables.

§ Estimated to be zero.

In summary, with the exception of the direct price elasticity of supply for mutton, the estimated farm price, inventory and supply elasticities reported in this section appear satisfactory on *a priori* grounds and exhibit similarities with other estimates reported in the literature. The price effects on quantities supplied and inventory levels indicate complex intertemporal relationships and complex intercommodity and inter-inventory relationships. Supply and inventory response to prices over the sample period were inelastic. However, given the marked fluctuations of farm prices, prices are important causal variables. The area of improved pastures and seasonal conditions are important shifters of the supply and inventory functions.

5 DERIVED REDUCED FORM RELATIONS

From the estimated structural relations reported in section three a set of reduced form relations are derived. The reduced form equations express the fourteen current endogenous variables in terms of lagged endogenous variables and exogenous variables. They may be used to evaluate some dynamic properties of the behaviour patterns of the N.S.W. livestock sector and for prediction purposes. The discussion in this section will focus on the time patterns of response of farm prices, the annual supplies of livestock products and the annual changes in cattle and sheep inventory levels to changes in the export price of beef, the wool price, the area of improved pastures and the index of annual rainfall.

5.1 DERIVATION OF THE REDUCED FORM RELATIONS

In deriving the reduced form relations a number of operating assumptions designed to linearize the structural relations and to ensure conformability of the variables are imposed. They are as follows:

(a) The structural model includes stochastic equations for the farm prices of lamb (22), beef (23) and mutton (24), product supply equations for beef (28), veal (30), lamb (35), mutton (34) and wool (33), inventory equations for North Coast dairy cows (25), beef cows (26), steers (27), adult sheep (31) and ewes mated to British breed rams (32) and an equation for calf slaughter (29), and identity relations for the inventory of dairy cows (29) and the specification of expected prices (1).

(b) The price variability measures VP_L and VP_B are treated as predetermined variables as a simplifying assumption.

(c) In the farm price relations the kg per capita operator is specified in terms of 1 000 tonnes supplied for a population of 4·5 million, i.e. kg (·) in (22) and (23) is specified at ·2222.

(d) The price ratio terms P^*_i/P^*_j are approximated by the linear terms of a Taylor series expansion at average 1960–70 levels, i.e.

$$P^*_i/P^*_j \approx \bar{P}_i/\bar{P}_j + (1/\bar{P}_j)(\cdot 5\, P_i + \cdot 33\, P_{i-1} + \cdot 17\, P_{i-2})$$
$$- (\bar{P}_i/P^2_j)(\cdot 5\, P_j + \cdot 33\, P_{j-1} + \cdot 17\, P_{j-2})$$

where $\bar{P}$ denotes average value of the price variable over the decade 1960–70.

(e) The inventory ratio term (K_B/K_D) is approximated by the linear terms of a Taylor series expansion at average 1960–70 levels.

It should be noted that these operating rules introduce a number of approximations. Further, these approximations are likely to be satisfactory for only a restricted subset of values of the price variables at around average 1960–70 values.[35] For values of the variables outside this subset the linear approximations imposed by (d) and (e) will introduce large residual errors.

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[35] For a discussion of this and related issues on the use of Taylor series expansions for linearising functions *see* Wormack and Matthews [37].

In a more general analysis a number of sets of reduced form relations would be derived. Each set of relations would be derived for a different expansion vector in the linearisation process of (d) and (e). In the interest of brevity, the remainder of this section is restricted to a set of reduced form relations applicable for average values of the price variables and the cattle inventory variables for the decade 1960–70.[36]

Given these operating assumptions the structural model of the N.S.W. livestock sector can be expressed as a linear function of current endogenous, lagged endogenous, exogenous, and unknown additive error variables, viz.

$$(42)\quad A_1 y + A_2 y_{-1} + A_3 y_{-2} + Bx + u = 0$$

where y is a vector of endogenous variables, x is a vector of exogenous variables, u is a vector of error terms[37] and A_1, A_2, A_3 and B are estimated structural coefficient matrices.

Estimates of the expected values of the coefficients of the reduced form model are given as:

$$(43)\quad y = \Pi_1 y_{-1} + \Pi_2 y_{-2} + \Pi_3 x$$

where $\Pi_1 = -A_1^{-1}A_2$, $\Pi_2 = A_1^{-1}A_3$ and $\Pi_3 = -A_1^{-1}B$

are the estimated reduced form coefficient matrices and all other terms are as defined for (42). Estimates of the coefficients of the Π matrices in (43) for average 1960–70 conditions are reported in appendix D. The signs and magnitudes of the estimated reduced form coefficients can be interpreted in terms of the estimated structural model discussed above. In the following section selected subsets of these coefficients and some dynamic multipliers are discussed.

5.2 SOME DYNAMIC PROPERTIES OF THE MODEL

The discussion of this section considers the time response patterns of some endogenous variables to a one period change in the values of some exogenous variables, i.e. the pattern of response of endogenous variables y_t over the current and subsequent periods, t, $t + 1$, $t + 2$, . . ., following a change in the value of one of the exogenous variables x_t in the current period. The method of analysis involves the calculation of dynamic multipliers.

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[36] Estimates of the reduced form coefficients for different expansion points, including average 1972–73 values of the variables, are available on request from the author.

[37] Strictly speaking this vector will include the residual term of the Taylor series expansion.

To facilitate the analysis the estimated set of reduced form equations (43) (a set of second order difference equations) is transformed into a set of first order difference equations. Following Theil and Boot [30]:

$$(44) \quad \begin{bmatrix} y_t \\ y_{t-1} \end{bmatrix} = \begin{bmatrix} \Pi_1 & \Pi_2 \\ I & O \end{bmatrix} \begin{bmatrix} y_{t-2} \\ y_{t-2} \end{bmatrix} + \begin{bmatrix} \Pi_3 \\ O \end{bmatrix} x_t$$

or, in compact form

$$(44a) \quad y^*_t = A^*y^*_{t-1} + B^*x_t$$

where y, x, Π_1, Π_2 and Π_3 are as defined for (43), I is an identity matrix and O is a null matrix.

Some stability and cyclical properties of the reduced form model (24) can be inferred from the characteristic roots of the matrix A^*.[38] The dominant (largest) roots are a pair of conjugate complex roots, $\lambda_1, \lambda_2 = {\cdot}163 \pm {\cdot}444i$, whose modulus is ·473. These roots describe a stable dynamic system whereby following an exogenous disturbance the system converges to an equilibrium position.

Following Goldberger [16 pp., 373–6] the dynamic multipliers are calculated as

$$(45) \quad M_r = \{m_{ijr}\} = A^{*r}B^* \text{ for } r = 0, 1, 2, \ldots$$

where $m_{ijr} = dy_{it+r}/dx_{jt}$ specifies the response of endogenous variable y_i in period $t + r$ to a change in the level of exogenous variable x_j in period t, and A^* and B^* are as defined for (44a). When $r = 0$ the multiplier is termed an impact multiplier and is the estimated reduced form coefficient. When $r > 0$ the multiplier is termed an interim multiplier. It should be noted that the dynamic multipliers (45) are only sample estimates of the true multipliers since they depend on the sample estimated coefficients of the A^* and B^* matrices. Also, the estimated multipliers are dependent on the validity of the assumptions employed in specifying the relations in the structural model (discussed in section two) and on the credibility of the mean estimates of the parameters of these relations (discussed in sections two and three).

Tables 5 through 8 contain estimates of some dynamic multipliers for the export price of beef, the price of wool, the index of annual rainfall and the area of improved pastures. The tables describe the response of average annual farm prices (beef, lamb and mutton), of annual supplies of livestock products (beef, lamb, mutton and wool) and of closing livestock inventory levels (beef cows, adult sheep and ewes mated to British breed rams) in the current year (period 0) and the next 4 years (periods 1, 2, 3 and 4) to a specified change in the levels of the exogenous variables in the current year.

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[38] The estimated non zero characteristic roots of A^* assessed at average 1960–70 values were: $\lambda_1, \lambda_2 = {\cdot}163 \pm {\cdot}444i$ (where $i = \sqrt{-1}$); $\lambda_3 = -{\cdot}415$; $\lambda_4, \lambda_5 = {\cdot}165 \pm {\cdot}276i$; $\lambda_6, \lambda_7 = -{\cdot}176 \pm {\cdot}096i$; $\lambda_8 = -{\cdot}176$; $\lambda_9 = {\cdot}001$.

In interpreting the dynamic multipliers in tables 5 through 8 the recursive nature of the structural model of the livestock sector[39] and the interdependence relationships between the different sheep and cattle activities are important. The time pattern of response of the farm price of beef, the annual quantity of beef supplied and the closing inventory of beef cows to a 10 cents per kg rise in the export price of beef illustrates some aspects of the operation of the recursive relationships. From table 5 the current period impact of the export price rise is to increase the average farm price of beef (by about 10 cents). This price rise induces producers to expand their breeding herds (by about 89,000) and some of this expansion comes at the cost of a drop in current production (by about 7 000 tonnes). In the next 2 years (periods 1 and 2) the increased cattle inventory levels result in increases in beef production (by about 2 500 and 5 000 tonnes in periods 1 and 2, respectively). The increased production depresses prices in these years (by about 1 and 3 cents/kg in periods 1 and 2, respectively). The falling beef prices induce producers to reduce the rate of expansion of the beef cow inventory and in periods 3 and 4 they actually reduce the inventory level.

TABLE 5

Estimates of Impact and Interim Multipliers for a 10 cents/kg Rise in Export Price of Beef on Some Endogenous Variables

Endogenous variables	Period multipliers†				
	0	1	2	3	4
Farm Prices (cents/kg):					
Beef	9·953	−·120	−·327	−·240	−·031
Lamb	·185	·139	−·057	−·073	−·029
Quantity Supplied (1 000 *t*):					
Beef	−6·964	2·655	4·932	3·616	·324
Lamb	−·164	−·890	−·360	−·077	·079
Mutton	2·920	·089	−·291	−·681	·004
Wool (million kg) ..	·006	−4·160	−2·694	−1·245	·207
Inventory Levels (million):					
Beef Cows	·089	·063	·027	−·046	−·028
Adult Sheep	−·617	−·399	−·184	·031	·018
Lamb Breeding Ewes ..	−·068	−·028	−·013	−·001	−·007

† Calculated according to equation (45) in the text. *See* text for interpretation of the multipliers.

The dynamic multipliers are influenced by the competitive relationships between wool and beef production, wool and lamb production and between beef and lamb production, and by the complementary relationship between beef and mutton production (where the latter is inversely related to changes in the inventory of adult sheep). For example, in table 5 expansion of the inventory of beef cows induced by an increase in the export price for beef is associated with a reduction in the sheep inventory. The latter reduction leads to an increase in the mutton supply and to a decrease in the supplies of wool and lamb.

[39] For more details of the recursive structure of the model *see* section 2.1.

In interpreting the dynamic multipliers for the price of wool (table 6) the relationship between the price of cull sheep and the price of wool has important implications. Since the price of cull sheep is positively related to the price of wool as shown in (24), the expansionary effects of rising wool prices on the inventory of adult sheep and on the supply of wool are partly offset by the associated higher salvage values for cull sheep. In fact, the current period effect of a 10 cents/kg rise in the price of wool is to reduce the inventory of sheep (by about 180,000) and the annual supply of wool (by about 250,000 kg). However in the next 2 years both the inventory of sheep and the supply of wool rise and these increases result in a net longer term expansion of the wool industry.

TABLE 6

Estimates of Impact and Interim Multipliers for a 10 *cents/kg Rise in the Price of Wool on Some Endogenous Variables*

Endogenous variables	Period multipliers				
	0	1	2	3	4
Farm Prices (cents/kg):					
Beef	−·168	·584	·365	·183	−·053
Lamb	−·065	1·184	·670	·252	−·187
Mutton	1·061	..	..	..	..
Quantity Supplied (1 000 *t*):					
Beef	3·105	−3·568	−3·036	−1·923	·231
Lamb	·057	−4·377	−2·457	−·848	·773
Mutton	−1·424	−1·302	·198	·343	−·049
Wool (million kg) ..	−·264	·819	2·188	·448	−·231
Inventory Levels (million):					
Beef Cows	−·040	−·022	−·072	·012	·017
Adult Sheep	−·177	·166	·061	−·039	−·011
Lamb Breeding Ewes ..	−·350	−·124	−·073	·099	·018

The time response of the farm price, annual quantity supplied and inventory variables to changes in the index of annual rainfall (table 7) and the area of improved pastures (table 8) is interesting. These exogenous variables are employed as proxy measures of available pasture fodder in the study. The initial (current year) impact of an increase in pasture fodder is to increase the inventory of livestock of all types. In the case of improved seasonal conditions the supply of all commodities also increases in the current year, but, in the case of an increase in the area of improved pastures supplies of livestock products do not increase until the following (period 1) and subsequent years. The increased supplies cause reductions in the farm prices of beef and lamb since these prices are in part a function of supplies. However wool and cull sheep prices remain unaffected as the former is assumed to be exogenous and the latter is a function of exogenous variables. These assumptions about the formation of farm prices and the movements in farm prices explain the tendency for supplies of beef and lamb to fall in periods 2, 3 and 4 (with the exception of beef in period 2 following an increase in the area of improved pastures) following the initial expansionary effects of increased pasture fodder. Given the assumptions embodied in the structural model the time response of the price, supply and inventory variables to an increase in pasture fodder are consistent with prior notions.

TABLE 7

Estimates of Impact and Interim Multipliers for a Unit Increase in the Index of Annual Rainfall† on Some Endogenous Variables

Endogenous variable	Period multipliers				
	0	1	2	3	4
Farm Prices (cents/kg):					
Beef	−1·117	−·777	·064	·089	·046
Lamb	−·579	−1·696	·196	·194	·127
Quantity Supplied (1 000 t):					
Beef	13·040	4·212	−·404	−·745	−2·867
Lamb	·511	6·370	−·793	−·742	−·510
Mutton	2·749	2·122	·030	·104	·053
Wool (million kg) ..	26·360	5·805	·555	·315	·060
Inventory Levels (million):					
Beef Cows	·014	−·013	−·007	−·001	·001
Adult Sheep	·870	·088	·002	·007	−·007
Lamb Breeding Ewes ..	·471	−·185	−·014	−·023	·030

† The index was specified as plus one (annual rainfall in deciles nine and ten), zero (deciles four through eight), minus one (decile three), minus two (decile two), and minus three (decile one).

TABLE 8

Estimates of Impact and Interim Multipliers for a million hectare Increase in the Area of Improved Pastures on Some Endogenous Variables

Endogenous variable	Period multipliers				
	0	1	2	3	4
Farm Prices (cents/kg):					
Beef	..	−6·811	·054	·441	·379
Lamb	..	−13·800	1·093	1·145	1·097
Quantity Supplied (1 000 t):					
Beef	..	42·530	2·240	−3·056	−2·266
Lamb	..	50·990	−4·970	−4·525	−4·433
Mutton	..	15·230	−·073	·236	·473
Wool (million kg) ..	..	38·990	2·298	1·603	·779
Inventory Levels (million):					
Beef Cows	·285	−·054	−·040	−·015	·005
Adult Sheep	5·842	·380	·251	·104	−·036
Lamb Breeding Ewes ..	4·030	−1·252	−·729	−·256	·206

In summary, the estimated dynamic multipliers indicate that external shocks to the N.S.W. livestock sector, including changes in export meat prices, wool prices, seasonal conditions and the area of improved pastures, have significant and far reaching effects on the performance of the livestock sector as specified by changes in farm prices, the quantities of livestock products supplied, and the inventory levels of cattle and sheep. The effects of these external shocks extend over several years and involve complex interrelationships between the prices, quantities and inventory levels of the various sheep and cattle activities.

6 CONCLUDING COMMENTS

The primary purpose of this study has been to measure major relationships describing the responses of farm prices, quantities supplied and inventory levels in the N.S.W. cattle and sheep sector to changes in economic and pastoral conditions. In this section we conclude with some observations concerning extensions of the model and some areas of application for the model.

The model could be expanded to embrace more sections of the Australian economy or it could be treated as a component of a larger and more embracing econometric model. An interesting extension would involve relaxing the assumption of a predetermined level of improved pastures and adding relations for the arable crop industries. Presumably the area of improved pastures would be related to the expected profitability of livestock activities, the expected profitability of crop activities, seed and fertilizer costs, and technology.[40] If, as one would expect, the first of these explanatory variables has a significant positive coefficient, the long run inventory and supply elasticities of the augmented model would be greater than the intermediate elasticities reported in tables 2 and 3.

Applications of the model include forecasting and policy analysis. Forecasts of future supplies and prices will aid decision-makers, both private and public, in making short run and long run decisions. In the case of livestock producers these decisions include the planning of investments or disinvestments in breeding livestock. The effectiveness of decision-making by abattoir operators, meat exporters, and other agribusiness firms will be facilitated by information on future supplies. In particular, the quantitative assessments made in table 7 of the current period and longer-term effects of drought conditions on product supplies should be of importance to these firms. When using the model for forecasting purposes the user should be aware of the restrictive assumption of constancy of the underlying structural model in the sample and forecast periods. As more information becomes available it should be used to update and revise the estimated parameters of the forecasting equations.

[40] In a recent study Duncan [12] obtained satisfactory results from regressing the area of improved pastures on the real cost of improved pastures (superphosphate price index/average greasy wool price) and dummy variables for major pasture technology changes.

A variety of models ranging from graphic comparative static techniques to simulation procedures could use the quantitative estimates reported in this study to evaluate the effects of alternative policy programmes on such variables as prices, quantities supplied, inventory levels and gross returns. These programmes include changes in the parity of international currencies, price support programmes, and export subsidies and taxes. In the following paragraphs we will evaluate some of the likely effects of the imposition of a tax on beef exports.

The direct effect of a tax on beef exports would be to lower the price received by beef exporters. In the notation of our model this can be represented by respecifying the return received by domestic beef exporters, $P^e{}_B$, as

(46) $P^e{}_B = P^{e'}{}_B\,(1 - A) - \beta$

where A is the *ad valorem* tax (subsidy), β is the per unit tax (subsidy), and $P^{e'}{}_B$ is the world export price. The effects of a beef export tax on farm prices of beef and lamb, on the annual production levels of beef, lamb and mutton and on the annual inventory of beef cows and sheep in N.S.W. can be evaluated with the aid of table 5. The effects will be discussed in terms of 2 time periods; first, the current year effects (period 0 of table 5) and second, the longer-term effects of a sustained tax on beef exports over several years (sum of periods 0 through 4 of table 5).

Suppose a per unit tax on beef exports of ten cents a kg is imposed, i.e. in (46) $A = 0$ and $\beta = 10$. In the current period we would expect average farm prices of cattle to fall by about 10 cents a kg and farm prices of lamb to fall by about ·25 cent a kg. Some of these price reductions would be passed on to domestic consumers.[41] Associated with these price changes would be changes in the annual supplies of meat products and in the annual growth of inventory levels. The export tax would induce increases in the levels of beef and lamb slaughter by about 7 000 and 2 000 tonnes a year, respectively, but it would induce a reduction in the level of mutton slaughter by about 3 000 tonnes a year. The rate of growth of the beef cow inventory would fall by about 90,000 a year while the rate of growth of the sheep inventory would increase by about 600,000 a year. These inventory changes modify some of the longer-term implications of a tax on beef exports.

Continuation of the 10 cents per kg tax on beef exports for several years would depress farm beef prices by about 9 cents per kg, have little effect on farm lamb (and also mutton) prices, reduce the rate of growth of the inventory of beef cows by about 100,000 a year and increase the rate of growth of the sheep flock by about 1·1 million a year. Clearly, a tax on beef exports would lower domestic prices at the retail and farm level, depress the returns to and growth of the N.S.W. beef industry, and foster expansion of the sheep industry.

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[41] Marceau's [23] study provides evidence that movements in farm prices are reflected in retail price movements.

APPENDIX A: LIVESTOCK INVESTMENT DECISION MODEL

In this appendix some details of the investment decision model which underlies the specified relations for the annual supply of livestock products and the relations for the closing inventories of livestock are provided.

In essence livestock producer decision making is cast into the framework of a discrete, multiperiod mathematical optimization problem. This problem involves choice of values for a time sequence of decision variables which will maximize an objective function subject to a set of constraints.

It is assumed that the producers' principal decision variables are the volumes of each product Q_i $(i = 1, . . ., m)$ to forward to market each year and the closing inventory of different livestock K_j $(j = 1, . . ., n)$ to retain for future production.

It is assumed that producers attempt to maximise the expected utility of a stream of annual net returns from livestock activities. Net return is specified as gross returns less running costs where running costs exclude costs associated with pasture and other quasi-fixed producer resources. As a simplification it is assumed that the aggregate producer utility function can be described by a quadratic function in the net return variables. The arguments of the objective function of the investment model of livestock decision making will hence include terms measuring the expected values and the expected variance terms of the uncertain elements in livestock production, namely market prices.

In algebraic terms, the aggregate objective function for livestock producers may be stated as the maximization of

$$(1)\ J = \{E(N_1, N_2, . . ., N_T),\ Var\ (N_1, N_2, . . ., N_T)\},$$

with

$$(2)\ N_t = \sum_i P_{it}\, Q_{it} - RC\,(K_{1t}, . . ., K_{nt}, C_t) - AC\,(\Delta K_{1t}, . . ., \Delta K_{nt}),$$

where N_t = net farm income in period t, $(t = 1, T)$,

P_i = farm price received for product i,

Q_i = quantity supplied of product i,

K_j = inventory of livestock j,

C = vector of purchased input prices,

$RC(\cdot)$ = running cost function, and

$AC(\cdot)$ = adjustment cost function.

Here E is the expectation operator, Var is the variance operator and Δ is the change operator.

Constraints on producers' decisions are of two types—resource limitations and technical production factors. These constraints, together with the opening livestock inventory, delineate the livestock production possibility surface.

It is assumed that the most important limiting resource in livestock production is the availability of pasture forage.

The technical constraints include livestock birth and death relations, output production relations and an inventory accounting relation. The quantity of meat supplied depends on the number of livestock slaughtered and also on slaughter weights with the latter assumed to be influenced by available pasture. The quantity of wool produced will depend on the number of sheep shorn and on available pasture. The inventory accounting relation specifies the closing inventory of livestock in terms of the opening inventory, births, deaths and sales of livestock over the accounting period.

In algebraic terms the important constraint functions may be stated as:

(3) $g(K_{1t}, \ldots, K_{nt}) \leqslant PR_t$,

(4) $K_{jt} = (1 + B_j - D_j) K_{jt-1} - S_{jt}$,

(5) $Q_{it} = f_1(S_{jt}, PR_t)$ for $i \neq$ wool,

(6) $Q_{it} = f_2(K_{jt-1}, PR_t)$ for $i =$ wool, and

(7) K_{j0} given

where PR = pasture resources,

B_j = birth rate for livestock j,

D_j = death rate for livestock j,

S_j = number of livestock j sold, and

Q_i and K_j are as defined above.

In general terms the decision problem is to maximize (1) for the decision variables K_j and Q_i subject to the constraints (2) through (7). At least conceptually, from the solution one can derive expressions for these decision variables for period t in terms of the current state of the system K_{t-1}, the availability of pasture resources PR_t, the vector of purchased input prices C_t, and producers' probabilistic information about current and future farm product prices $E(P_t, P_{t+1}, \ldots)$ and $Var(P_t, P_{t+1}, \ldots)$. With the progression from one decision period to the next producers will use new information generated to revise their probabilistic information about market prices.

APPENDIX B: DEFINITION AND CLASSIFICATION OF VARIABLES AND DATA SOURCES

ENDOGENOUS VARIABLES

P_B — Average farm beef price—\$ per 100 kg (227–317 kg first and second export quality, Homebush, July–June) [1].

P_L — Average farm lamb price—\$ per 100 kg (13–16 kg first and second export quality, Homebush, July–June) [1].

P_M — Average farm cull sheep price—\$ per 100 kg (18–23 kg export quality, Homebush, July–June) [1].

$K_{D \cdot N}$ — Cows, heifers and heifer calves intended for production of milk and cream in North Coast statistical division—1000 (31st March) [5].

K_B — Other cows and heifers mainly for beef in N.S.W.—1000 (31st March) [5].

K_S — Bullocks and steers on non-milk holdings of N.S.W.—1000 (31st March) [5].

K_{AS} — Sheep 1 year and over in N.S.W.—million (31st March) [5].

K_L — Intended matings of ewes to British breed rams in N.S.W.—million (31st March) [6].

Q_B — Annual production of beef in N.S.W.—1 000 tonnes (bone-in-weight, July–June) [5].

Q_V — Annual production of veal in N.S.W.—1 000 tonnes (bone-in-weight, July–June) [5].

Q_L — Annual production of lamb in N.S.W.—1 000 tonnes (bone-in-weight, July–June) [5].

Q_M — Annual production of mutton in N.S.W.—1 000 tonnes (bone-in-weight, July–June) [5].

Q_W — Annual production of wool in N.S.W.—million kg (greasy weight basis, July–June) [5].

CLS — Calves slaughtered in N.S.W.—1,000 (July–June) [5].

EXOGENOUS VARIABLES

P_W — Average price realized for greasy wool at N.S.W. auctions—cents/kg (July–June) [5].

P_D — Average net butter return to farmers in N.S.W.—cents/kg (July–June) [5].

$P^e{}_B$ — Average export price for beef—\$ per 100 kg (July–June) [4].

$P^e{}_L$ — Average export price for lamb—\$ per 100 kg (July–June) [4].

$P^e{}_M$ — Average export price for mutton—\$ per 100 kg (July–June) [4].

$K_{D \cdot O}$ — Cows, heifers and heifer calves intended for production of milk and cream in N.S.W. other than North Coast—1,000 (31st March) [5].

IP — Area of improved pastures in N.S.W.—million hectares (31st March) [25].

W — Rainfall index—*see* relation (3) in the text.

T — Time—$T = 1$ for 1953–54, $T = 2$ for 1954–55, etc.

Y — Personal disposable income per capita for Australia—dollars (July–June) [5].

APPENDIX C: ESTIMATES OF MEAN VALUES

	Explanatory variables†						*Current*
		Product supply variables				Inventory	
		Q_B	Q_V	Q_W	Q_L	Q_M	K_B
y_{-1}	P_{L-1} ..	·0048	−·0031	·0276	−·7357	−·0017	−·0614
	P_{B-1} ..	−·4838	−·0565	·0004	−·0114	·2029	6·1740
	K_{B-1} ..	·1423	·0070	−·0002	·0049	−·0033	−·1001
	$K_{D \cdot N-1}$	·1440	·0366	−·0002	·0059	−·0039	−·1210
	K_{S-1} ..	·1420	·0009	−·0002	·0047	−·0031	−·0958
	K_{AS-1}	·1085	·0132	6·7500	·1007	2·8680	−1·3850
	K_{L-1} ..	·3442	·0526	−·0954	12·1600	−·1454	−4·3930
y_{-2}	P_{L-2} ..	·0025	−·0016	·0143	−·3789	−·0009	−·0317
	P_{B-2} ..	−·2492	−·0291	·0002	−·0058	·1046	3·1810
x	K‡ ..	−260·4	−24·16	−53·15	48·47	−36·56	1,409·0
	P^e_B ..	−·6964	−·0813	·0006	−·0164	·2920	8·887
	P^e_L ..	·0035	−·0022	·0202	−·5358	−·0012	−·0448
	P^e_M ..	..	..	−2·7710	..	..	..
	P_w ..	·3105	·0014	−·0264	·0057	−·1424	−3·962
	P_{w-1} ..	·2049	·0009	·1974	·0038	−·0940	−2·615
	P^f_{w-2} ..	·1055	·0005	·1016	·0019	−·0485	−1·347
	P^*_D ..	·0789	·0005	−·0001	·0026	−·0017	−1·007
	VP_B ..	..	..	..	..	..	−32·280
	VP_L ..	−·0379	−·0058	·0105	−1·340	·0160	·4840
	W ..	13·04	−·6046	26·36	·5112	2·7490	13·37
	IP ..	..	..	..	..	..	284·7
	T ..	..	..	2·528	..	..	..
	Y ..	−·0010	−·0002	·0005	−·0121	·0004	·0130
	$K_{D \cdot O-1}$	·1440	·0366	−·0002	·0059	−·0040	−·1210

* Assessed for values of the price variables at average 1960–70 levels. The estimates are valid only for values of price variables in the vicinity of average 1960–70 levels.

† Definitions of the variables and their units of measurement are given in appendix B.

‡ Constant term.

OF REDUCED FORM COEFFICIENTS*

endogenous variables†

variables			Farm price variables				
K_{DN}	K_S	K_{AS}	K_L	P_B	P_L	P_M	CLS
−·0608	−·0734	·0003	·0793	·0367	·1728	..	−·0799
−1·1190	−1·353	−·0429	−·0047	·0315	·0129	..	−1·471
·0186	·1127	·0007	−·0004	−·0115	−·0056	..	·1107
·0225	−·2408	·0008	−·0005	−·0139	−·0067	..	1·092
·0178	·0215	·0007	−·0004	−·0110	−·0053	..	·0234
·2607	·3151	·0096	−·0095	−·1610	−·1139	..	·3424
1·0430	1·261	·0308	−·2686	−·6443	−2·8640	..	1·370
−·0379	−·0379	·0002	·0409	·0193	·0890	..	−·0411
−·5767	−·6971	−·0221	−·0024	·0162	·0066	..	−·7576
530·2	809·7	41·67	−4·234	49·86	40·13	−11·86	−646·1
−1·611	−1·948	−·0617	−·0068	·9953	·0185	..	−2·117
−·0443	−·0535	·0002	·0578	·0274	·6066	..	−·0582
..	..	−·4073	..	..	..	·9017	..
·0273	·0330	−·0177	−·0350	−·0168	−·0065	·1059	·0358
·0180	·0218	·0199	−·0231	−·0111	−·0043	..	·0236
·0093	·0112	·0103	−·0119	−·0057	−·0022	..	·0122
2·063	·0119	·0004	−·0002	−·0061	−·0030	..	·0130
..	..	..	..	..	..	..	..
−·1149	−·1389	−·0034	·1624	·0709	·3155	..	−·1510
1·808	8·835	·8698	·4709	−1·1170	−·5787	..	−15·75
..	..	5·842	4·030	..	..	..	..
−10·86	..	..	..	..	..	..	..
−·0036	−·0043	−·0001	·0013	·0022	·0137	..	−·0046
·0225	−·2410	·0008	−·0005	−·0139	−·0067	..	1·092

APPENDIX D: ALTERNATIVE ESTIMATES OF SOME STRUCTURAL EQUATIONS

Some variables in the economic model specification were omitted from the preferred estimated functions reported in section three. This appendix records estimates of those equations when all variables in the economic model specification are included. Equation numbers correspond to those in the text.

Farm Price of Cull Sheep

$$\text{(24a)}\quad P_M = \underset{(10{\cdot}719)}{-8{\cdot}693} + \underset{(\cdot 2229)}{\cdot 8063}\, P^e{}_M + \underset{(\cdot 0385)}{\cdot 1251}\, P_W + \underset{(\cdot 2168)}{\cdot 0286}\, kg\,(Q_M)$$

$$- \underset{(\cdot 0758)}{\cdot 1002}\, kg\,(Q_L + Q_V + Q_B) + \underset{(\cdot 0031)}{\cdot 0031}\, Y$$

Closing Inventory of North Coast Dairy Cows

$$\text{(25a)}\quad K_{D{\cdot}N} = \underset{(62{\cdot}25)}{784{\cdot}79} - \underset{(141{\cdot}9)}{251{\cdot}6}\, P^*{}_B / P^*{}_D - \underset{(3{\cdot}650)}{10{\cdot}158}\, T - \underset{(\cdot 4255)}{\cdot 1830}\, W$$

Closing Inventory of Adult Sheep

$$\text{(31a)}\quad K_{AS} = \underset{(3{\cdot}61)}{44{\cdot}03} - \underset{(4{\cdot}54)}{11{\cdot}19}\, P^*{}_B / (\cdot 9\, P^*{}_W + \cdot 1\, P^*{}_L) - \underset{(\cdot 1350)}{\cdot 4327}\, P_M + \underset{(\cdot 3656)}{\cdot 0077}\, VP$$

$$+ \underset{(\cdot 4402)}{\cdot 7932}\, W + \underset{(1{\cdot}050)}{5{\cdot}735}\, IP$$

Annual Wool Production

$$\text{(33a)}\quad Q_W = \underset{(47{\cdot}90)}{-29{\cdot}79} + \underset{(1{\cdot}001)}{6{\cdot}890}\, K_{AS-1} + \underset{(\cdot 777)}{2{\cdot}391}\, T + \underset{(3{\cdot}05)}{26{\cdot}65}\, W$$

$$\underset{(105{\cdot}3)}{-301{\cdot}0}\, P_M / (\cdot 9\, P^*{}_W + \cdot 1 P^*{}_L) - \underset{(1{\cdot}140)}{\cdot 521}\, VP_W$$

Annual Mutton Production

$$\text{(34a)}\quad Q_M = \underset{(36{\cdot}13)}{-59{\cdot}30} + \underset{(12{\cdot}75)}{56{\cdot}29}\, P^*{}_B / (\cdot 9\, P^*{}_W + \cdot 1\, P^*{}_L) - \underset{(\cdot 8171)}{\cdot 9083}\, P_M$$

$$+ \underset{(\cdot 685)}{2{\cdot}873}\, K_{AS-1} + \underset{(2{\cdot}317)}{3{\cdot}001}\, W$$

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