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SUPPLY RESPONSE IN THE AUSTRALIAN SHEEP INDUSTRY: A PROFIT FUNCTION APPROACH*

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Profit function models for the three major regions in which the Australian sheep industry operates are specified and estimated. The supply response elasticity estimates are made using a normalised quadratic functional form and time series cross-sectional data. Elasticity estimates, together with their confidence intervals, are presented for the pastoral, wheat-sheep and high rainfall zones. In general, the supply response elasticity estimates derived in this study are lower than those previously reported for studies in which little or no account has been taken of the multi-product nature of Australian agriculture.

Various types of econometric models of Australian agricultural production systems have been built in the past. Despite the fact that most production systems are characterised by multi-output firms, this characteristic has been included explicitly in only a limited number of Australian studies. The recent exceptions are those models constructed by Vincent, Dixon and Powell (1980), McKay, Lawrence and Vlastuin (1982, 1983) and used by Adams (1987). (For recent overseas examples, see Ball 1988; Shumway, Saez and Gottret 1988.) Most of the models employed have been single equation production function or output supply response models. In this work, the approach has been to study a single output, such as wheat, or to combine all outputs into an aggregate index. Because production decisions about one output in Australian broadacre agriculture are likely to depend on decisions about other outputs, concentrating on a single output is likely to lead to specification error in a single equation supply response model that takes no account of the multi-output nature of the firm. In the case where all outputs are aggregated into a single index, information about the relationships between outputs is lost. In either case, the validity of the estimates of important parameters, such as supply response elasticities, is called into question. In addition, forecasts from such models are likely to be misleading because proper account has not been taken of the relationships between one output and others.

In this paper, an attempt is made to overcome some of these problems in the case of supply response estimates for the three major regions of the Australian sheep industry. Regional supply response estimates based on time series cross-sectional data are presented for the first time. In addition, confidence intervals for these estimates are estimated. The results are derived using a profit function model based on the normalised quadratic functional form. The model used is outlined in the following section. The data are then described and elasticity estimates presented for the pastoral, wheat-sheep and high

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rainfall zones. These estimates are then compared with those reported in previous studies.

The Model

Given certain regularity conditions and the assumption of profit maximisation, it can be shown, using duality theory, that a multiple input, multiple output production system, such as the sheep industry, can be completely characterised by a profit function model (Lau 1978*a*; McFadden 1978). A review of the theory of production with emphasis on its use in supply response analysis is provided in Wall and Fisher (1988). Given a profit function, output supply and input demand equations can be derived using Hotelling's Lemma (Hotelling 1932) by differentiating with respect to prices. To implement this process empirically it is necessary to first specify a form for the profit function. In the present case the normalised quadratic, a member of the class of flexible functional forms, was adopted.

To simplify the mathematical expression of the functional form both output and variable input quantities are included in the vector Y. Thus, Y is a 'netput' vector where positive values are outputs and negative values are variable inputs. Also, both output and input prices are included in the vector P and both fixed inputs and other exogenous factors are included in the vector Z.

The profit function for the normalised quadratic is:

$$(1) \qquad \Pi/P_m = \alpha_0 + \sum_{i=1}^{m-1} \alpha_i(P_i/P_m) + \sum_{i=m+1}^{n} \alpha_i Z_i + 1/2 \sum_{i=1}^{m-1}\sum_{j=1}^{m-1} \alpha_{ij}(P_i/P_m)(P_j/P_m) + 1/2 \sum_{i=m+1}^{n}\sum_{j=m+1}^{n} \alpha_{ij} Z_i Z_j + \sum_{i=1}^{m-1}\sum_{j=m+1}^{n} \alpha_{ij}(P_i/P_m)Z_j$$

and the output supply and input demand equations are expressed as:

$$(2) \qquad \partial(\Pi/P_m)/\partial(P_i/P_m) = Y_i = \alpha_i + \sum_{j=1}^{m-1} \alpha_{ij}(P_i/P_m) + \sum_{j=m+1}^{n} \alpha_{ij} Z_j \qquad \forall i = 1, \ldots, m-1$$

where m is the total number of variable inputs and outputs and $(n-m)$ is the total number of fixed inputs and other exogenous factors.

On the basis of production theory (see Wall and Fisher 1988) it is expected that for the estimated profit function the properties of homogeneity, symmetry, monotonicity and convexity should hold. Homogeneity in prices is maintained in equations (1) and (2) and hence cannot be tested. If the profit function is twice continuously differentiable, then its second-order partial derivatives should be invariant to the order of differentiation. For this symmetry restriction to hold the following must be true:

$$(3) \qquad \alpha_{ij} = \alpha_{ji} \qquad \forall i, j = 1, \ldots, m$$

The monotonicity and convexity properties do not necessarily hold. The consistency of the estimated model with the properties of convexity and monotonicity has to be evaluated after estimation. For the normalised quadratic form to satisfy the monotonicity condition the estimated values of output supply and input demand must be positive. To satisfy the convexity condition the Hessian of price derivatives must be positive semi-definite.

The Data Set

Combined time series cross-sectional data were obtained from the economic surveys of the sheep industry which were conducted by the then Bureau of Agricultural Economics for the years 1967-68 to 1980-81. To be included in the sheep industry a property must have carried at least 200 sheep. Properties where a significant proportion of income was derived from stud or dealing activities were not included in the survey. The survey data consisted of farm data, but it was not possible to follow individual farms through time. Individual properties could only be distinguished according to the state and agricultural zone in which they resided.

It is useful to be able to identify the agricultural zone in which a property is situated because the three main zones in Australia (the pastoral, wheat–sheep and high rainfall zones) have different output and input mixes. The pastoral zone is the largest zone and includes the arid and semi-arid regions of all the mainland states except Victoria. Because of inadequate and unreliable rainfall, cropping is generally impractical except in areas adjacent to the wheat–sheep zone. Livestock are grazed extensively on native pastures. While stocking rates in the pastoral zone are low, the properties are very large compared with those in the other two zones. Water is usually supplied by bores and dams. The main output in the pastoral zone is wool, followed by sheep, cattle and finally crops. Wheat sales provide the major income source in the crops category.

The wheat–sheep zone covers a portion of each of the five mainland states. Given the rainfall and topography it is generally possible to produce crops and improved pastures as well as to conduct more intensive grazing than occurs in the pastoral zone. Wool was the major output followed by crops in the wheat–sheep zone in the late 1960s and early 1970s. However, during the mid 1970s there was a trend toward more cropping and in 1980-81, crops, predominantly wheat, contributed the major proportion of total output. Because crop production requires relatively more machinery than livestock production the expenditure on fuel, oil and grease increased over the sample period. In the early 1970s producers in the pastoral zone spent more on fuel, oil and grease than producers in the other zones. However, by the end of the 1970s producers in the wheat–sheep zone had the largest expenditure in this category because of the trend toward cropping.

The high rainfall zone covers the greater part of the eastern, south-eastern and south-western coastal belt excluding most of Queensland but including all of Tasmania. This zone has higher rainfall and hillier topography than the wheat–sheep zone and hence is more suitable for intensive grazing and fodder crops but less suitable for cereal grains. Production in this zone is orientated more toward livestock than production in the wheat–sheep zone. The major output in the high rainfall zone is wool followed by sheep meat, beef cattle and crops. Unlike the other two zones wheat is not the dominant crop grown.

Model Specification

For the multiple input, multiple output specification of the production technology set of the sheep industry, $F(Y; Z)$, the following initial aggregates were defined: wool output (Y_{WL}); total sheep output (Y_{SO}); total cattle output (Y_{CO}); wheat output (Y_{WH}); other crops output (Y_{OC}); total crop output (Y_{TC}); labour input (Y_{LA}); materials and services input (Y_{MS}); sheep input (Z_{SI}); cattle input (Z_{CI}); capital input (Z_{KA}); land input (Z_{LA}); technical change (Z_{TI}); January to June rainfall (Z_{R1}); July to December rainfall (Z_{R2}); wheat delivery quotas (Z_{QU}); and Z_{D1}, Z_{D2}, Z_{D3}, Z_{D4} are cross-sectional dummies.

The variables included in the normalised quadratic specification for each zone were as follows:

Pastoral zone

(4) $\Pi(P_{WL}, P_{SO}, P_{CO}, P_{WH}, P_{OC}, P_{VI}; Z_{SI}, Z_{CI}, Z_{KA}, Z_{LA}, Z_{TI}, Z_{R1}, Z_{R2}, Z_{QU}, Z_{D1}, Z_{D2}, Z_{D3})$

Wheat–sheep zone

(5) $\Pi(P_{WL}, P_{SO}, P_{CO}, P_{WH}, P_{OC}, P_{VI}; Z_{SI}, Z_{CI}, Z_{KA}, Z_{LA}, Z_{TI}, Z_{R1}, Z_{R2}, Z_{QU}, Z_{D1}, Z_{D2}, Z_{D3}, Z_{D4})$ and

High rainfall zone

(6) $\Pi(P_{WL}, P_{SO}, P_{CO}, P_{VI}; Z_{SI}, Z_{CI}, Z_{KA}, Z_{LA}, Z_{TI}, Z_{R1}, Z_{R2}, Z_{D1}, Z_{D2}, Z_{D3}, Z_{D4})$

where P_{VI} is the price of variable inputs, and the other variables are as defined above. Further details of the variables are discussed below.

The main difference in the specification for each zone was that crops were divided into wheat and other crops in the pastoral and wheat–sheep zone models whereas the aggregate, total crops, was specified for the high rainfall zone model. Only three cross-sectional dummy variables were included in the pastoral zone model whereas the models of the other two zones have four cross-sectional dummies. This is because the pastoral zone covers four states whereas the other two zones cover five states.

Output supply and input demand equations were derived for each zone by applying Hotelling's Lemma to (4), (5) and (6). The normalised quadratic system of the profit, output supply and input demand equations (1 and 2) was estimated. The price of materials and services was used as the numeraire. As a consequence, the demand equation for materials and services inputs was not estimated as part of the system.

In order to estimate the model it is necessary to assume a stochastic structure. It was assumed that any deviations of the observed profit, output supply and input demand from their profit-maximising levels were due to random errors in optimisation and that the disturbances were additive and followed a multivariate normal distribution with a zero mean and a constant contemporaneous covariance matrix.

All prices in the specification are expected prices. When expected prices rather than actual prices are specified, producers can be assumed to be maximising expected profits subject to expected output prices. The application of Hotelling's Lemma then gives output supply and input demand equations as a function of these expected prices. Thus, these output supply and input demand equations have a different interpretation from the traditional functions which are usually specified as functions of actual prices.

Measuring the Variables

The data for each surveyed property were grouped according to the zone and the state in which the property resided. The average-per-property data for each zone–state group were used to calculate the price and quantity measures. The averages were weighted averages with the weights depending on how typical a particular property is of the whole industry. The use of weighted averages means that the final results are representative of the sheep industry and that the effects of measurement error and sampling bias recorded in the individual property data are reduced.

For the models of each zone there were 14 years of data, but the number of cross-sectional units varied because each zone covers a different number of states. The result of the groupings means that for the pastoral zone models there were 56 observations, and for the wheat–sheep zone and high rainfall zone models there were 70 observations.

Output quantities

Wool output was measured as the number of adult sheep shorn plus 33 per cent of the number of lambs shorn. A figure of 33 per cent was chosen because, on average, lambs yield 33 per cent as much wool as adult sheep (Australian Bureau of Statistics 1982). Wheat and other crop outputs were measured as the number of hectares harvested. The other crops category included barley, oats, other grains, oilseeds, hay, fruit and vegetables. Total crop output was measured as the total number of hectares of crops harvested.

The theory of decision making for livestock producers was discussed by Jarvis (1974) and Reynolds and Gardiner (1980). On the basis of this theory, it is clear that livestock supply equations are better modelled by a disaggregated specification where it is possible to differentiate between adult males, adult females and younger animals. Unfortunately, it was not possible to divide sheep output into either adults and lambs or wethers and ewes for all the years in the data set. Neither could cattle output be divided between adults and calves, or cows, steers and heifers. Hence, only total numbers could be used to calculate sheep and cattle outputs.

Total sheep output was measured as the net increase in sheep numbers. This is equal to the number sold minus number purchased plus closing numbers minus opening numbers. The result of this calculation was a measure of the net increase in sheep numbers whether they were sold or kept on the property. Total cattle output was measured in a similar manner.

McKay *et al.* (1982, 1983) defined livestock output as the number sold plus closing numbers minus opening numbers. Livestock input was measured as the number purchased plus opening numbers. When closing minus opening numbers was negative, that is, there was an operating loss, the result was interpreted as a 'running down of the capital stock' (see Lawrence and McKay 1980). When this occurred the absolute value of closing minus opening numbers was added onto the value of livestock inputs. The inclusion of purchases and operating losses as inputs is unsatisfactory. Both purchases and operating losses are dependent on output prices and hence are not exogenous as is assumed in the model specification.

It is important to measure the effects of different rates of increase in yields over the time period being studied. In order to test for an upward trend in crop yields and fleece weights, wheat and wool yields were linearly regressed against time and weather variables. The time variable was a linear time trend and the weather variables were rainfall levels. These variables are discussed in more detail below. Unfortunately, wheat yields could not be derived from the survey data for all the years being studied and so yields collected by the Australian Bureau of Statistics on a state basis were used to test for a trend in yields. Wool yields were calculated from the survey data by dividing kilograms of wool produced by the number of sheep shorn. Separate regressions were estimated for each state in each zone in the case of wool and for each state in the case of wheat. The resultant equations were used to determine if there was a statistically significant trend in yields. Where the trend was not statistically significant yields were assumed to have remained constant over the time period under study. The estimated yield trends were included in the model by multiplying the estimated trend in yields by the number of sheep shorn and the area of wheat harvested variables. The resultant series was taken to represent the expected average wool and wheat outputs in kilograms and tonnes respectively. It was not possible to calculate a similar series of yield trends for sheep, cattle and other crops.

Output prices

Wool, sheep and cattle output prices were derived implicitly by dividing the value of sales by the quantity of each output sold. This meant that the output prices for each cross-sectional unit were different, thus accounting for price variation between states. Derrick and Wolken (1986) have shown that failing to account for interregional price variation can bias elasticity estimates. Because the value of crop sales recorded in the survey data does not refer to the actual crop output for that year, the same procedure could not be used to calculate crop prices. Wheat prices were measured by an index of wheat prices (Bureau of Agricultural Economics 1982). Crop prices for the other crops category in the pastoral and wheat–sheep zones were defined as the 'other grains price' index (Bureau of Agricultural Economics 1982). The other grains price index measures the prices of all grain crops excluding wheat. This index, rather than the all crops price index, was used because a very large proportion of the crops grown in these two zones consisted of grains. The all crops price index (Bureau of Agricultural Economics 1982), rather than the total grains price index, was used to measure the price of other crops for the high rainfall zone because grains were not the major crop sown in this zone.

Producers respond to expected and not actual prices. The difficulty is deciding how to define expected prices in terms of observable variables. In this study, expected prices were assumed to be defined as a two-year moving average (defined over the current and past year) of the implicit prices for wool, sheep and cattle outputs. For wheat and other crops a decision was taken to specify two alternative measures and, on the basis of goodness of fit, statistical significance and signs of the parameters, to choose one measure. The two measures were the actual price and a two-year moving average of prices. The use of a two-year moving average of output prices for wool, sheep and cattle meant that the number of available observations was reduced. In the pastoral zone, this meant that there were 52 observations available for estimation. In the wheat–sheep and high rainfall zones there were 65 observations available.

Simultaneity bias may arise in some cases as a consequence of including the current price in the specification of the expected price. However, in the present case the bias is unlikely to be important, first because output at the farm level will have little or no effect on prices, and second because for many of the broadacre products considered in the supply equations prices are determined on world markets in which Australian production constitutes a small share.

Variable input prices

There were two inputs considered to be variable over the time span of one year; these were materials and services, and labour. Materials and services is a general classification for a range of inputs including: repairs to plant; repairs to structures; livestock materials; pesticides and sprays; fodder; fertiliser; seed; packaging materials; freight inwards; electricity; fuel, oil and grease; insurance; rates and taxes; accounting charges; advisory services; rent; interest paid; and other services and contracts. The individual items within the materials and services category were aggregated into one price index using the Tornqvist index. The prices used for each of the items in the aggregate were obtained from the Bureau of Agricultural Economics index of prices paid (Bureau of Agricultural Economics 1982) and the value weights were the payments to each category. The Bureau's price series for fertilisers does not account for changes in the fertiliser subsidy. Therefore, ex-works fertiliser prices which include the fertiliser subsidy were used (Rose, Moir, Farquharson and Vanzetti 1984). An alternative to using one index for all materials and services is to measure separately the major components of the materials and services category, such as fuel and fertiliser, and include them as separate equations in the model. While such an approach could potentially give more information about changes in input mix it had the practical disadvantage of increasing the number of parameters to be estimated beyond what was possible given the available data set.

Labour inputs into farm production are made up of three types: operator labour, which is relatively fixed over a year; family labour; and hired labour. Partner's labour was ignored because the number of weeks worked by the partner is not reported continuously in the survey data. Operator's labour is probably the most difficult input to measure accurately. For many of the surveyed producers the operator's labour input over a year was recorded as 50 weeks. This meant that the variable was almost constant. Furthermore, the difference in the quality of decisions between different operators can lead to important differences in production outcomes. Ideally, it would be more accurate to split the operator's contribution into two parts, physical labour and managerial input. Some researchers such as Lopez (1984) have attempted to measure managerial ability by the education of the operator. Unfortunately, such data were only collected in the later sheep industry surveys. Because of the problems with measuring the operator's managerial input, the assumption was made that managerial ability did not vary across the cross-section or through time. There are also problems when measuring family labour. The quality of work put in by family members is highly variable and it is difficult to put an opportunity cost on family labour because it is not known whether it was younger children working in the school holidays or an older member of the family working a full week. Because of the problems with measuring the physical labour of the operator and the family labour inputs they were both assumed to be constant over the cross-section and through time. The result is that both operator and family labour inputs are accounted for in the intercept term.

Unfortunately, a complete price series for hired labour could not be derived from the data. Total yearly payments to labour in terms of wages and in terms of stores and rations were recorded in the survey data but in some years the number of weeks worked by hired labour was not recorded. Hence, the Bureau of Agricultural Economics price index for labour was used to measure the price of hired labour. Further payments to hired labour were for shearing and crutching. The price of labour used for shearing and crutching was approximated by dividing total payments for shearing and crutching by average sheep numbers. The two labour price series, that is, hired labour and shearing and crutching, were aggregated into a single index using the Tornqvist index, with total payments to each category being used as the weights.

It was found that the partial correlation coefficient between the price of variable labour and the price of materials and services was very close to unity. To overcome this problem, the prices of variable labour and materials and services were aggregated into a single series, called the price of variable inputs, using the Tornqvist index. An implicit quantity index to measure the quantity demanded of variable inputs was derived by dividing the total value of materials and services and variable labour by the variable inputs price index.

Quantity of variable inputs demanded

The quantities demanded of the two variable inputs, materials and services and labour, could not be measured directly but were defined implicitly as the total value divided by the price index. Thus, the quantity of labour demanded was the total value of shearing and crutching plus hired labour divided by the Tornqvist price index for labour. The quantity of materials and services demanded was the total value of materials and services divided by the Tornqvist price index for materials and services.

Quantity of fixed inputs

Quantity measures were required for the fixed inputs, sheep, cattle, capital and land. These inputs are durable inputs in the sense that they are not completely consumed in the year of purchase but provide a flow of services over several years. The cost of the service flow from these inputs consists of the following components: opportunity cost; depreciation; maintenance; and capital gain. Maintenance expenditures are not included in these calculations but are included in the materials and services category. The problems of including capital gains are discussed in Paul and Abey (1984). Capital gains were treated as an unrealised output in this study and hence were not included in the calculations. The quantities of the service flows from sheep, cattle, capital and land were assumed to be proportional to the actual quantities. Sheep, cattle and land quantities were measured directly and capital quantities were measured implicitly.

The quantity of the service flow from sheep and cattle inputs was measured as the opening numbers on the property. The quantity of the service flow from land was approximated by the average land area. It was not possible to account for quality differences caused by such things as soil erosion and fertility because of the nature of the data.

Taxation concessions such as accelerated depreciation and the investment allowance were available to producers during much of the time period under study. Such allowances have the effect of lowering the price of capital. The accelerated depreciation allowance gave primary producers a special depreciation rate on eligible assets above that which is normally allowed. The investment allowance allowed primary producers to deduct a certain proportion of their capital expenditure from their taxable income. Because of the need to adjust the service flow of capital inputs for these taxation concessions an implicit quantity index was calculated for capital inputs. This was derived by dividing the value of the service flow from capital by the price index for capital. In a perfect market the price of the service flow can be measured by the rental price. Since data on rental prices were not available the method outlined by Fisher (1974) was used to calculate a price series for capital inputs.

Other exogenous factors

Other variables measured were technology, weather and the effects of government policy. These are factors which are beyond the producer's control but still affect profits. Technology was approximated by a linear time trend. The effect of weather on production decisions was measured by rainfall variables for two separate periods. The first period was defined as the 6 months, January to June, immediately preceding each financial year and the second period was defined as the first 6 months of each financial year, that is, July to December. These two periods were chosen because they roughly matched the pre-season and growing periods for the winter wheat crop. In addition, the first period includes autumn rainfall which Easter (1975) found to be an important period of rainfall for livestock production. In order to calculate the amount of precipitation that fell in each zone of each state it was necessary to match up the Bureau of Meteorology regions with the Australian Bureau of Agricultural and Resource Economics definitions of the pastoral, wheat-sheep and high rainfall zones.

The main government policy which affected the decisions of producers in the sheep industry during the time period under study was the setting of wheat delivery quotas which operated between 1969-70 and 1973-74. Wheat delivery quotas were measured as the inverse of the effective quota for that year (Smith and Brennan 1978). Quotas in the year 1969-70 were not included in the analysis because they were probably announced too late in the season to affect planting decisions (Fisher 1975; Smith and Brennan 1978).

Results

The model was estimated using a full information maximum likelihood estimator (Wymer 1977). An attempt to estimate the model with the profit function included in the specification was not successful. This was because the number of parameters in the profit equation was large and the Hessian matrix became ill-conditioned. As a consequence, the profit function was dropped from the specification,

TABLE 1

Estimated Parameter Values for the Normalised Quadratic Model of the Pastoral Zone[a]

Variable	Wool	Sheep	Cattle	Wheat	Other crops
Wool price	0·29	−0·13	−0·04	0·00	0·07
	(2·86)	(1·17)	(0·56)	(0·01)	(0·71)
Sheep price	−0·13	2·84	−1·85	0·02	−0·26
	(1·17)	(1·82)	(2·30)	(0·06)	(2·43)
Cattle price	−0·04	−1·85	2·83	0·16	0·17
	(0·56)	(2·30)	(3·94)	(0·88)	(2·46)
Wheat price	0·00	0·02	0·16	1·99	0·31
	(0·01)	(0·06)	(0·88)	(4·26)	(1·50)
Other crop price	0·07	−0·26	0·17	0·31	0·13
	(0·71)	(2·43)	(2·46)	(1·50)	(0·36)
Sheep input	2·58	0·40	8·15	0·30	0·07
	(13·94)	(0·12)	(4·53)	(0·78)	(0·47)
Cattle input	−0·23	−1·65	5·11	0·20	0·14
	(3·79)	(1·59)	(8·68)	(1·51)	(2·89)
Capital input	−0·07	4·45	−4·78	1·89	0·64
	(0·39)	(1·51)	(2·93)	(4·45)	(4·03)
Land input	0·31	1·97	−4·66	−0·86	−0·40
	(1·91)	(0·72)	(3·01)	(2·58)	(3·13)
Time trend	0·84	−14·64	7·24	10·74	3·53
	(0·86)	(1·18)	(0·92)	(4·63)	(3·86)
Rain 1	0·21	5·81	1·18	0·18	0·09
	(2·63)	(4·40)	(1·62)	(1·10)	(1·45)
Rain 2	0·07	0·42	0·93	0·52	0·12
	(1·11)	(0·38)	(1·53)	(3·69)	(2·27)
Wheat quotas				−0·03	−0·03
				(0·87)	(2·08)
Dummy 1	1·09	13·51	−6·53	−0·04	−0·43
	(3·55)	(2·53)	(2·18)	(0·06)	(1·75)
Dummy 2	0·95	10·16	−7·31	−1·48	−0·76
	(2·83)	(1·77)	(2·25)	(2·10)	(2·81)
Dummy 3	1·24	13·47	−4·54	−0·48	−0·23
	(5·66)	(3·54)	(2·13)	(1·05)	(1·32)
Intercept	1·95	1·00	−3·69	−14·28	−4·10
	(1·58)	(0·07)	(0·40)	(4·71)	(3·41)

[a] t-statistics for each coefficient appear in parentheses.

resulting in some loss of efficiency. However, multicollinearity problems were reduced.

Many of the parameter estimates on the price variables for the crops equation in the high rainfall zone did not agree with *a priori* expectations. This problem may have arisen because the wide range of different crops sown in the high rainfall zone could not be consistently aggregated. When the crops equation was dropped from the system, the parameter estimates on the other equations did not change markedly. Cropping is not a major activity in the high rainfall zone, except perhaps in South Australia. Only 4 to 10 per cent of the total land area was sown to crops in all states, except South Australia, over the time period under study. In South Australia the level was 6 to 16 per cent. Because crops were not an important activity in the high rainfall zone and because the other parameter estimates were stable when cropping

TABLE 2

Estimated Parameter Values for the Normalised Quadratic Model of the Wheat–Sheep Zone[a]

Variable	Wool	Sheep	Cattle	Wheat	Other crops
Wool price	0·31	0·05	−0·21	−0·32	−0·39
	(1·24)	(0·21)	(1·55)	(1·55)	(2·68)
Sheep price	0·05	1·39	0·08	0·92	−0·13
	(0·21)	(3·38)	(0·39)	(3·85)	(0·94)
Cattle price	−0·21	0·08	0·27	−0·35	0·24
	(1·55)	(0·39)	(1·73)	(2·27)	(2·84)
Wheat price	−0·32	0·92	−0·35	1·15	−0·61
	(1·55)	(3·85)	(2·27)	(3·21)	(2·74)
Other crop price	−0·39	−0·13	0·24	−0·61	0·54
	(2·68)	(0·94)	(2·84)	(2·74)	(1·33)
Sheep input	7·52	1·06	−1·39	0·04	−0·31
	(22·73)	(1·43)	(3·74)	(0·12)	(1·84)
Cattle input	−0·20	−0·18	2·18	0·09	0·09
	(1·63)	(0·76)	(17·07)	(0·74)	(1·39)
Capital input	−0·42	0·29	−1·03	1·49	0·30
	(1·56)	(0·51)	(3·53)	(5·01)	(1·99)
Land input	0·10	0·12	0·37	0·31	0·01
	(0·64)	(0·34)	(2·06)	(1·89)	(0·12)
Time trend	−1·92	3·49	−1·92	3·47	2·22
	(1·21)	(1·29)	(1·21)	(1·83)	(2·14)
Rain 1	0·14	0·34	−0·58	0·05	0·05
	(0·78)	(0·92)	(3·13)	(0·32)	(0·60)
Rain 2	0·11	−0·20	0·76	0·31	0·13
	(0·74)	(0·59)	(4·51)	(2·07)	(1·56)
Wheat quotas				−0·08	−0·02
				(2·50)	(1·09)
Dummy 1	−0·27	−0·43	−0·88	−0·89	−0·74
	(0·99)	(0·74)	(2·98)	(3·36)	(5·42)
Dummy 2	−0·07	−1·49	−1·50	0·17	−0·56
	(0·21)	(2·15)	(4·31)	(0·54)	(3·43)
Dummy 3	−0·77	−3·94	−1·23	−1·69	−0·94
	(2·53)	(5·90)	(3·64)	(5·41)	(5·72)
Dummy 4	−0·17	−2·24	−1·61	−0·91	−0·07
	(0·55)	(3·20)	(4·56)	(2·80)	(0·40)
Intercept	3·14	−1·76	5·06	3·93	−0·93
	(1·57)	(0·53)	(2·65)	(1·56)	(0·67)

[a] *t*-statistics for each coefficient appear in parentheses.

activities were excluded, the total crops harvested equation and its price was dropped from the system.

The parameter estimates from the regression models of the three zones are given in Tables 1, 2 and 3. These models maintained the homogeneity and symmetry hypotheses. Nearly one-half of the estimated parameters were statistically significant at the 5 per cent level. This is reasonable for supply systems models of this size. The Carter–Nagar (1977) R^2 statistic was used as a measure of goodness of fit. The values of this statistic for the pastoral, wheat–sheep and high rainfall zones were 0·94, 0·96 and 0·95 respectively. It follows that the models for each zone had a high degree of explanatory power.

As mentioned above, for the monotonicity condition to hold in the normalised quadratic model the estimated quantities of output supply must be positive at all data points. This condition held for the models of both the wheat–sheep and high rainfall zones. However, in the case of the model for the pastoral zone there were four data points for which the condition did not hold.

For the convexity property to hold, the Hessian matrix must be positive semi-definite. This property was tested by hypothesis tests on the signs of the Cholesky values of the Hessian matrices for the models

TABLE 3

Estimated Parameter Values for the Normalised Quadratic Model of the High Rainfall Zone[a]

Variable	Wool	Sheep	Cattle
Wool price	0·33	−0·90	0·25
	(1·26)	(3·25)	(1·57)
Sheep price	−0·90	1·80	−0·67
	(3·25)	(3·68)	(2·88)
Cattle price	0·25	−0·67	0·73
	(1·57)	(2·88)	(3·96)
Sheep input	9·32	5·65	1·71
	(17·10)	(5·82)	(3·07)
Cattle input	−0·34	0·05	4·86
	(1·33)	(0·10)	(19·12)
Capital input	0·64	0·84	−0·54
	(1·86)	(1·38)	(1·51)
Land input	0·50	0·27	−0·26
	(1·00)	(0·30)	(0·51)
Time trend	3·54	7·79	−1·18
	(2·18)	(2·95)	(0·79)
Rain 1	0·41	0·92	−0·24
	(1·95)	(2·46)	(1·13)
Rain 2	0·15	−0·69	0·31
	(0·62)	(1·58)	(1·23)
Dummy 1	−0·18	−0·54	−0·35
	(0·76)	(1·32)	(1·47)
Dummy 2	0·92	−0·22	0·00
	(3·21)	(0·42)	(0·01)
Dummy 3	1·69	0·10	0·18
	(5·41)	(0·18)	(0·57)
Dummy 4	0·49	−2·43	−0·63
	(1·92)	(5·34)	(2·41)
Intercept	−5·17	−7·78	0·18
	(2·75)	(2·53)	(0·11)

[a] t-statistics for each coefficient appear in parentheses.

of the three zones (Lau 1978*b*). In all cases, the hypothesis of convexity was not rejected.

Analysis of the estimates for the pastoral zone showed that, in general, own-price parameters were statistically significant and that the cross-price parameters were not statistically significant determinants of output supply decisions. However, for the wheat–sheep and high rainfall zones both the own-price and cross-price variables were important determinants of output supply decisions.

The sheep input parameter was statistically significant with a positive sign in the wool equation in all three models. However, in the pastoral and wheat–sheep zone models, the sheep input variable was not statistically significant in the sheep output equation. This is probably because the relevant measure of sheep input in these zones is the number of breeding ewes rather than total sheep opening numbers. The sheep input parameter was positive and statistically significant in the cattle equation for the pastoral and high rainfall zone models. This result was unexpected. The cattle input parameter had a positive sign and was statistically significant at the 5 per cent level in the cattle output equation in all three models.

The capital input parameter had a statistically significant and positive sign in the wheat and other crops equations because these activities are more capital intensive than livestock activities. The land input parameter had statistically significant negative coefficients in the cattle, wheat and other crops equations in the pastoral zone models. This is probably because the larger properties in the pastoral zone tend to be in the less productive country where there is relatively less cropping, and cattle and more sheep per property are carried.

The signs on the rainfall parameters were usually positive except for the January to June rainfall variable in the cattle equation in the wheat–sheep and high rainfall zone models. Generally, the parameter on the January to June rainfall variable tended to have a higher value than the parameter on the July to December rainfall variable in the livestock equations. The opposite result occurred in the crops equations.

The wheat quotas coefficient had a negative sign in the wheat equation but the sign on the equivalent coefficient in the other crops equation was also negative. It was expected that the sign on this coefficient would be opposite to that for the wheat quotas coefficient in the wheat equation because producers moved some land to other crops when wheat quotas were introduced. Other researchers have also had problems with including a wheat quotas variable in output supply studies (Fisher 1975; Vincent *et al.* 1980). Fisher (1975) concluded that this was evidence that the quotas were largely inoperative during the latter part of the wheat delivery quota scheme.

When a normalised quadratic form is specified, homogeneity is maintained and cannot be tested (see equation 2). The symmetry restrictions, subject to homogeneity, were tested using the likelihood ratio test. The likelihood ratio test is based on the test statistic, $-2\ln\lambda$, where λ is the ratio of the unrestricted to the restricted maximum likelihood. Under the statistical assumptions of the model $-2\ln\lambda$ is asymptotically distributed as a chi-squared distribution with degrees of freedom equal to the number of restrictions tested.[1] The symmetry

[1]The likelihood ratio test is biased towards rejection of the null hypothesis (Laitinen 1978). For further discussion of the likelihood ratio statistic, see Engle (1984).

TABLE 4

Likelihood Ratio Tests of the Symmetry Restriction on the Normalised Quadratic Models

Zone	Likelihood ratio statistic	Critical value 5%	Critical value 1%
Pastoral	18·80	18·31	23·21
Wheat–sheep	21·14	18·31	23·21
High rainfall	12·40	7·81	11·34

restriction can also be tested using the Wald statistic. The Wald statistic is always greater than or equal to the likelihood ratio statistic (Berndt and Savin 1977). When the null hypothesis is true the difference between the two statistics decreases as the sample size increases (Breusch 1979). In all the hypothesis tests carried out in this study, the difference between the likelihood ratio statistic and the Wald statistic was not marked and, hence, only the likelihood ratio results are reported. The likelihood ratio test values for the symmetry restrictions, subject to the homogeneity condition, for the three zones are given in Table 4. For all three zones the symmetry restrictions were rejected at the 5 per cent level. However, the symmetry restrictions were not rejected for the pastoral and wheat–sheep models at the 1 per cent level.

The existence of heteroscedasticity in the normalised quadratic models was checked using two methods. First, plots of the residuals were visually inspected for any patterns across the observations and second, the Breusch–Pagan test (Judge *et al.* 1985, p. 423) was used. In order to perform this test, each of the equations in the models was estimated using ordinary least squares.

Visual inspection of the residual plots did not reveal any patterns across the observations. The chi-squared tests of the Breusch–Pagan statistic rejected homoscedasticity at the 5 per cent level for the wheat equation in the pastoral zone model and the cattle equation in the wheat–sheep zone model. However, in both of these cases homoscedasticity was not rejected at the 1 per cent level.

The existence of autocorrelation was checked using two methods. First, the Godfrey–Breusch framework was used (see Judge *et al.* 1985, p. 329). In order to use this framework, each of the equations in the models was estimated using ordinary least squares. The ordinary least squares residuals were regressed against all the regressors and the ordinary least squares residual itself lagged q periods. The t-statistic on the lagged residual is the Lagrange multiplier t-statistic for q-th order serial correlation. The Godfrey–Breusch framework can test for the existence of either autoregressive or moving average residual distributions but cannot discriminate between the two. The second method used to check for autocorrelation was to calculate the sample autocorrelations and their standard errors for each of the equations (see Judge *et al.* 1985, p. 319).

Because the data were combined time series and cross-sectional with four cross-sectional observations in the pastoral zone and five cross-sectional observations in the wheat–sheep and high rainfall zones, the models were checked for fourth-order autocorrelation in the pastoral zone model and fifth-order autocorrelation in the wheat–sheep and high rainfall zone models. None of the Lagrange multiplier t-statistics was significantly different from zero at the 5 per cent level. In addition, none of the sample autocorrelation estimates exceeded 1·96 times its standard error. It was therefore concluded that there was no significant autocorrelation in the models. It should be noted that since there were only 12 yearly observations there was little information on the time series properties of the residuals.

Price elasticities for the three zones

For the normalised quadratic, the own-price and cross-price elasticities can be measured by,

(4) $\eta_{ij} = \alpha_{ij} P_j / Y_i P_m \quad \forall \quad i, j = 1, \ldots, m-1$

The elasticities calculated at mean data values are given in Table 5. The own-price elasticity estimates had the expected signs and, with the exception of wheat in the pastoral zone, they were all less than unity. Wheat in the pastoral zone is largely grown as an 'opportunity crop' when physical and economic conditions are favourable and hence is quite likely to be more responsive to price changes. There was not a large difference in the magnitude of the own-price elasticity estimates across the zones. The only notable differences were that cattle and

TABLE 5

Estimated Own-Price and Cross-Price Elasticities

	Pastoral zone	Wheat–sheep zone	High rainfall zone
Wool–wool	0·10	0·04	0·19
Wool–sheep	−0·05	0·00	−0·04
Wool–cattle	−0·01	−0·03	0·03
Wool–wheat	0·00	−0·04	–
Wool–other crops	0·03	−0·05	–
Sheep–wool	−0·02	0·01	−0·11
Sheep–sheep	0·39	0·36	0·49
Sheep–cattle	−0·25	0·02	−0·13
Sheep–wheat	0·00	0·24	–
Sheep–other crops	−0·04	−0·03	–
Cattle–wool	0·00	−0·09	0·07
Cattle–sheep	−0·28	0·03	−0·13
Cattle–cattle	0·43	0·11	0·16
Cattle–wheat	0·02	−0·14	–
Cattle–other crops	0·03	0·10	–
Wheat–wool	0·00	−0·17	–
Wheat–sheep	0·03	0·50	–
Wheat–cattle	0·22	−0·19	–
Wheat–wheat	2·67	0·62	–
Wheat–other crops	0·42	−0·33	–
Other crops–wool	0·39	−0·55	–
Other crops–sheep	−1·44	−0·18	–
Other crops–cattle	0·94	0·34	–
Other crops–wheat	1·72	−0·86	–
Other crops–other crops	0·72	0·76	–

wheat outputs were both more elastic in the pastoral zone than in the other two zones.

Confidence intervals were calculated for the elasticity estimates. These are reported in Tables 6 and 7. The confidence interval calculations were based on Fieller's method which is described in Valentine (1979) and Miller, Capps and Wells (1984). The confidence

TABLE 6

Confidence Intervals of the Own-Price and Cross-Price Elasticities for the Pastoral and Wheat–Sheep Zones[a]

	Pastoral zone	Wheat–sheep zone
Wool–wool	0·03 to 0·18	−0·02 to 0·11
Wool–sheep	−0·12 to 0·03	−0·06 to 0·07
Wool–cattle	−0·06 to 0·03	−0·06 to 0·01
Wool–wheat	−0·11 to 0·11	−0·10 to 0·01
Wool–other crops	−0·04 to 0·09	−0·09 to −0·01
Sheep–wool	−0·05 to 0·01	−0·11 to 0·14
Sheep–sheep	−0·03 to 0·83	0·15 to 0·57
Sheep–cattle	−0·49 to −0·04	−0·08 to 0·12
Sheep–wheat	−0·07 to 0·07	0·12 to 0·36
Sheep–other crops	−0·07 to −0·01	−0·11 to 0·04
Cattle–wool	−0·03 to 0·01	−0·20 to 0·02
Cattle–sheep	−0·54 to −0·04	−0·13 to 0·19
Cattle–cattle	0·21 to 0·68	−0·02 to 0·24
Cattle–wheat	−0·03 to 0·08	−0·28 to −0·02
Cattle–other crops	0·01 to 0·05	0·03 to 0·18
Wheat–wool	−0·41 to 0·41	−0·40 to 0·05
Wheat–sheep	−0·68 to 0·72	0·24 to 0·77
Wheat–cattle	−0·28 to 0·74	−0·36 to −0·03
Wheat–wheat	1·40 to 4·38	0·24 to 1·02
Wheat–other crops	−0·13 to 1·02	−0·58 to −0·09
Other crops–wool	−0·70 to 1·53	−0·97 to −0·15
Other crops–sheep	−2·87 to −0·28	−0·59 to 0·21
Other crops–cattle	0·20 to 1·91	0·11 to 0·60
Other crops–wheat	−0·54 to 4·28	−1·52 to −0·25
Other crops–other crops	−3·34 to 4·89	−0·37 to 1·91

[a]Confidence intervals are calculated for the 95 per cent level.

TABLE 7

Confidence Intervals of the Own-Price and Cross-Price Elasticities for the High Rainfall Zone[a]

Wool–wool	−0·02 to 0·09
Wool–sheep	−0·16 to −0·04
Wool–cattle	−0·01 to 0·06
Sheep–wool	−0·22 to −0·06
Sheep–sheep	0·13 to 0·43
Sheep–cattle	−0·18 to −0·03
Cattle–wool	−0·01 to 0·11
Cattle–sheep	−0·22 to −0·04
Cattle–cattle	0·07 to 0·21

[a]Confidence intervals are calculated for the 95 per cent level.

TABLE 8

A Comparison of Alternative Own-Price Elasticity Estimates

	This study	VDP	FM	MLV
Pastoral zone				
Wool	0·10	0·08[a]	0·52	
Sheep	0·39	0·08[a]		
Cattle	0·43	1·00		
Wheat	2·67	2·65		
Other crops	0·72			
Wheat–sheep zone				
Wool	0·04	0·26	0·28	0·72[a]
Sheep	0·36	0·22	0·49	0·72[a]
Cattle	0·11	0·48	0·70	0·27[b]
Wheat	0·62	0·77	2·05	0·46[c]
Other crops	0·76	0·50[d]		
High rainfall zone				
Wool	0·04	0·06	0·26	
Sheep	0·28	0·62		
Cattle	0·14	0·34		

Note: VDP = Vincent, Dixon and Powell (1980); FM = Fisher and Munro (1983); MLV = McKay, Lawrence and Vlastuin (1982).

[a]Wool and sheep.
[b]Cattle and other outputs.
[c]All crops.
[d]Barley.

intervals derived using this method are not symmetric about the elasticity estimates. However, if the estimated coefficient is statistically insignificant then the confidence interval will include zero.

A summary of own-price elasticity estimates from other studies is given in Table 8. In general, the own-price elasticity estimates calculated in this study tended to be lower than those from other studies. For example, the own-price elasticity estimates for wool and sheep were lower than those reported by McKay *et al.* (1982). This difference may be due to either the differences in the specification of outputs, the functional form, or in the time period studied. In the McKay *et al.* (1982) study the time period was 1952–53 to 1976–77, a substantially longer period than the one used in the present study. In addition, McKay *et al.* (1982) employed a translog profit function.

About half of the normalised quadratic confidence intervals for the cross-price elasticities between crop and livestock activities did not include zero. This provides some evidence that the relationships between the cropping and livestock activities are stronger than other researchers such as Reynolds and Gardiner (1980) and Fisher and Munro (1983) have found. It is difficult to make further comparisons of the cross-price elasticity estimates with those from other studies because the comparisons are not strictly relevant. McKay *et al.* (1982, 1983) aggregated their outputs in a different manner from that used here and Vincent *et al.* (1980) excluded complementarity from their model. Hence, it is not surprising that some of the cross-price elasticity estimates are different.

An estimate of the aggregate supply elasticity for each of the three zones was calculated by taking a weighted sum of the own-price and cross-price elasticity estimates derived from each of the models. The weights were the output shares of each output in total revenue. For the pastoral, wheat–sheep and high rainfall zones the aggregated supply elasticities derived from the models were calculated to be 0·44, 0·20 and 0·00 respectively. The aggregate supply elasticity is highest for the pastoral zone because the own-price elasticity estimate for wheat in that zone is relatively large compared with the other price elasticity estimates.

The aggregate elasticity of supply estimates from this study can be compared with the estimate derived by Pandey, Piggott and MacAulay (1982) who used time series data for Australia to calculate the short-run aggregate supply elasticity for 1975–76 to be 0·34. Although their method assumed the existence of a single output Cobb–Douglas production function, their estimate of the aggregate supply elasticity was close to that found for the pastoral and wheat–sheep zones in the present study. The aggregate supply elasticity for the wheat–sheep zone of 0·01 calculated by Vincent *et al.* (1980) is very low compared with the estimates presented above.

Concluding Comments

A profit function model of the production system underlying the Australian sheep industry was specified and estimated. A profit function rather than a production function model was chosen because the profit function specification is less restrictive in the sense that non-jointness or output separability do not have to be maintained. In a profit function model, prices are specified as exogenous variables rather than input quantities as is the case when a production function approach is adopted. In the present case, survey data were available for individual producers. Because individual producers have no influence on output prices, the nature of this data set is more consistent with use in a profit rather than a production function model.

A further advantage with a profit function model is that the output supply and input demand functions can be easily derived as the first-order partial derivatives of the profit function. In addition, a profit function model can accommodate the fact that, over a one year period, some inputs are variable while other inputs are fixed. Other factors such as weather and government policy, which are stochastic and beyond the individual producer's control, can also be included in a profit function model. There was no need to match expenses on inputs with the production of certain outputs, a task that would not have been possible given the nature of the available data.

From the model estimates, it can be seen that expected relative output prices, relative variable input prices, quantities of fixed inputs, technological change and rainfall are all important influences on production decisions. Price elasticities were calculated and the own-price elasticity estimates were highest for wheat and other crops, with the estimate for wool usually the lowest. Except for wheat produced in the pastoral zone, all own-price and cross-price elasticity estimates were less than unity over the time period under study. Generally, the own-price elasticity estimates from this study were lower than those from previous studies. In addition, a larger number of significant cross-price effects were reported than has been commonly found in previous studies. These findings are important because policy makers who design programmes which are aimed at manipulating output prices should also account for the effect that the policy will have on the levels of other outputs. Because outputs are interrelated through prices, policy makers should ensure that the effects of one policy do not conflict with the policy decisions for other products. The fact that agricultural outputs are interrelated means that it is important that a comprehensive approach to agricultural policy be taken rather than the product-by-product approach which has tended to dominate agricultural policy making in Australia in the past.

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