Product Supply Elasticities for the Australian Broadacre Industries, Estimated with a Programming Model

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This paper reports on estimates of the supply response to price changes of Australian broadacre farmers using a programming model. The products examined were beef, sheep meat, wool and cereals. Medium-term own-price and cross-price elasticities were estimated from a designed experiment with the model. These elasticities are presented and discussed in the context of estimates from other studies.

Introduction

The output responses of farmers to price changes are of great importance for projections of probable future output and for assessing the probable effects of policies which result in price changes. Examples of these two uses of estimates of farmers' responses to price and other changes can be found in the Bureau of Agricultural Economics (BAE) medium-term supply projections (BAE 1979) and in an examination of the costs and benefits of subsidizing fertiliser use in Australia (BAE 1975, 1976*a*).

Two major directions of supply-response research can be distinguished. On the one hand, there are the so-called 'positive models', which attempt to say what will happen on the basis of past experience. In general, econometric models are positive because they are estimated by fitting observations of the dependent variables to observations of the independent variables. The medium-term projections of the BAE (1979), contain a number of examples of positive econometric models. Other Australian examples are those of Freebairn (1973), Gruen *et al.* (1967), Malecky (1975), Powell and Gruen (1967) and Vincent, Dixon and Powell (1980).

The alternative approach to supply-response analysis is to use a conditionally positive simulation model based on a normative model of the industry or region in question. The only rigorous empirical comparison made of the two approaches was not able to establish a preference for either (Shumway and Chang 1977). An example of a conditionally positive model can be found in the superphosphate studies (BAE 1975, 1976*a*), in which the Australian sheep, beef-cattle and wheat-growing industries were simulated using mathematical programming models, and the response to various levels of input and output prices was estimated. These models assumed that the farmers' objective was to maximize a measure of profit subject to physical, financial and behavioural constraints. A family of similar models has been built in the BAE for use in these and other studies. This paper reports on supply-response estimation using the most developed of the family of models, referred to as the Regional Programming Model (RPM). Another example of this type of model used in Australia is the Aggregative Programming Model of Australian Agriculture (APMAA) built at the University of New England and described in Walker and Dillon (1976).

In this paper, an application of the RPM to estimate national supply elasticities for cereals, beef, sheep meat and wool is presented. The aim and methodology of the study is similar to that of Wicks and Dillon (1978). The models used in the respective studies also have similarities in that they are large aggregate programming models of Australian agriculture. The RPM provides a more current estimate of supply elasticities, and also the opportunity to compare the elasticities of supply of major agricultural commodities from these two models.

The Regional Programming Model

The RPM simulates the aggregated product supply and input demand responses of the farms making up the Australian sheep, beef-cattle and cereal-growing industries, which together account for 63 per cent of the gross value of rural production in Australia and for 59 per cent of Australian rural establishments. Income estimates and some physical data based on surveys of these industries are published regularly by the BAE. For example,

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data for 1982-83 and projections to 1983-84 were published in February 1984 (Flavel and Tucker 1984).

The RPM is described in detail in Longmire *et al.* (1979). Examples of the application with earlier versions of the model are Cornell and Hone (1978) and Easter and Hall (1981). The current version of the model was applied to the issue of biological weed control in Menz *et al.* (1984). A number of structural changes have taken place in the model over time — regional boundaries have changed in line with the BAE Grazing Industry Survey regions, and the right-hand sides have been updated, as have prices and costs. Documentation of these changes is available from the authors. In brief, the model has a single large matrix with 507 rows and 1573 columns, the objective function of which is maximized using linear programming. This large matrix is made up of thirteen submatrices each representing a single region. Each submatrix has an appropriate choice of activities and resources to allow simulation of regional output patterns. Each regional submatrix can be further subdivided into parts modelling feed supply, cropping, sheep, beef cattle, labour, capital and investment. In addition, transportation and trading activities are provided to link the regions. Commodity sales and input purchases are modelled at the national level. For example, all beef-producing activities in all regions supply quantities of beef into a national pool, from which beef is sold at a set price and, correspondingly, each type of input is drawn from a single national pool for that input. This structure removes the need to calculate gross margins for activities independently of the model and simplifies changing the price regimes.[1]

The objective function maximizes the excess of returns over costs, taking no account of farmer reactions to risk either in prices or production. The flexibility constraints which were a feature of the original model have been removed. Nevertheless, the model can still be regarded as simulating medium-term supply response, on the basis of the 'flock/herd build-up' technical coefficients in the matrix. These coefficients reflect a five-year time horizon in that an increase of five in the national breeding flock in five-year's time requires one additional young animal per 'average' year. The model simulates changes from the existing production situation which is reflected in the right-hand sides (animal numbers, land areas etc.) rather than from a 'no production' base level. The opportunity cost associated with changing existing production patterns will thus prevent the model from being *radically* different from the existing situation and this influences the interpretation of the output as a medium term one. Note however that these right-hand side 'constraints' are in no sense arbitrary but reflect the realities of constraints to change over a five year period.

The model regions are delineated on the basis of climatic and agronomic studies so as to maximize within-region homogeneity. The main basis for disaggregation is the division of Australia into Pastoral, Wheat-Sheep and High Rainfall Zones, as used in the Bureau's Grazing Industries Survey. The zones are further subdivided by separating off Tasmania and Western Australia and by delineating climatic and growth patterns in northern and eastern Australia. Data for the approximately eight thousand coefficients in the model were derived from several sources, including State departments responsible for agriculture and CSIRO. The major source of data however was the Grazing Industries Survey.

Model Verification/Validation

Verification of the model's structure and coefficients was discussed briefly by Longmire *et al.* (1979, p. 70). The structure of the model has been verified by inspection and use by many researchers over its history. Verification of the model coefficients poses a more difficult problem, because of their number. Extensive checking has been undertaken over a period of years, but minor mis-specifications are inevitable in a model of this size.

Validation of a model's performance (output) is inherently subjective (Anderson 1974).

[1] While the model is regionally based, and the output provides information on the amount of each activity in each region, summary regional figures on net income, total animal numbers, total beef, wool etc. production are not automatically provided. Regional summaries can be obtained by hand calculation (extremely laborious) or by using a report writer. No report writer is currently available for the RPM.

One empirical technique, which can aid in the judgement of a model's validity, is a comparison between actual output and model output. This comparison is made in Table 1 where it can be seen that there is a reasonable correspondence between the two. (When examining Table 1, recall that 1982-83 cereal yields were substantially depressed by drought. The effects of abnormal climatic conditions are not captured by the model).

Table 1: Comparison of Actual and Model Output Levels: Australia

Product	Unit	Base model output	Actual output	
			1982-83	1981-82
Wool	kt	742	694	711
Mutton of which	kt	241	261	234
— hoggets and young sheep	kt	32	*na*	*na*
Lamb	kt	274	277	276
Live sheep	million	6.8	5.9	5.8
Beef and veal	kt	1336	1555	1573
Wheat	Mt	16.5	9.0	16.4
Barley	Mt	3.3	1.7	3.5
Oats	Mt	0.5	0.8	1.7

Base model solution obtained using 1982-83 prices. Actual output derived from ABS and BAE sources.

Another empirical test of the model's validity is to see whether product responsiveness to price change is in the expected direction. This supply responsiveness is the major focus of the paper. Suffice it to say at this point that *where there are strong expectations of a particular direction of supply response,* those expectations are fulfilled by the model results.

Validation of a model is dependent upon its intended use. The empirical comparisons referred to above and the authors' experiences in manipulating the model indicate that it is a valid tool for estimating supply response elasticities for Australian broadacre agriculture.

Experimental Method

The RPM model was used to estimate the medium-term production response of broadacre agriculture in Australia to output price changes. The types of production examined were cereals (wheat, oats, barley and sorghum), sheep meat (including the meat equivalent of live exports), beef (domestic and manufactured) and wool (cross-bred and merino). The prices varied were those appropriate to the four types of output. All cereal prices were varied equiproportionately. Similarly, the price of each category of sheep meat, beef and wool was also varied equiproportionately.

The prices for each treatment were set in a designed experiment in order to bring out the effects of own- and cross-prices on output of each product. This allowed for the interactions between, for example, wool prices and beef production, as well as the direct effects of wool price on wool production and beef price on beef production.

This procedure is similar to that adopted by Wicks and Dillon, who used a 5 x 5 x 5 complete factorial design in order to cover all the price permutations. The problem with a full factorial design is that it requires a large number of treatments. A full factorial design for the experiment reported here with four prices and with five levels of each price would have required 625 treatments (5 x 5 x 5 x 5). This is expensive in terms of the money cost of solving the programming models and in terms of the work needed to analyze the results. A more efficient design described by Cochrane and Cox (1957) is the Central Composite design, which requires only thirty-one treatments to cover four prices at five levels. There is some loss of information compared to a full factorial design, but this is compensated for by much lower costs of obtaining the solutions and of analyzing the experiment. A Central Composite design was used in this study.

The Central Composite design is illustrated in Figure 1, which shows a design with two independent variables, X_1 and X_2. This allows for a simple graphical presentation, which is impossible with four variables.

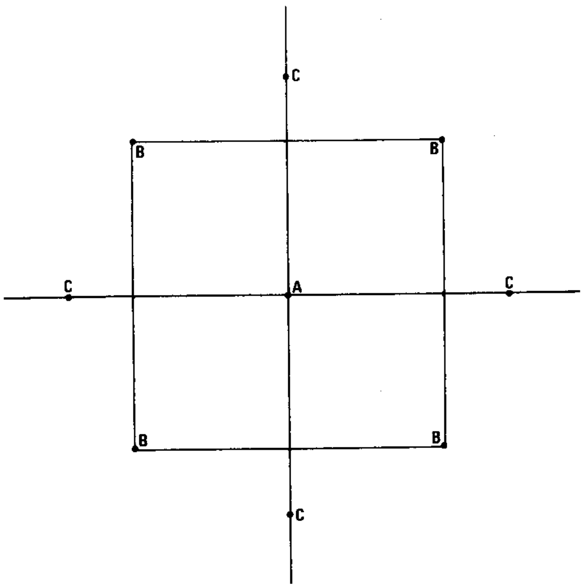

Figure 1: Central Composite Design

The point A where the axes intersect is the centre of the experiment, the base situation. It is replicated seven times. In the analysis presented here, this is the level 3 price in Table 2. The four points B are a 2x2 factorial; in this analysis, 2x2x2x2 = 16 combinations of prices, at one standard deviation above and below the base price (i.e. levels 2 and 4 in Table 2). Finally, the factorial is supplemented by the four points C which have one variable outside the range of the factorial and the rest at the base level. In this analysis, there are 2x4 = 8 such observations, set two standard deviations either side of the base price (i.e. levels 1 and 5 in Table 2). The prices used in the experiment are presented in Table 2. The base level of prices used were those prevailing in 1982-83. The two standard deviation range on each side of those prices encompasses both historical experience and future expectations about prices (Watson *et al.* 1983). Each of the 31 treatments provided one observation each of production of cereals, beef, sheep meat and wool at a given combination of prices. The observations were summarized using quadratic functions to approximate a response surface for each product. The equations had the general form:

$$Q = a + b_1W + b_2L + b_3B + b_4C + b_5W^2 + b_6L^2 + b_7B^2 + b_8C^2 + b_9WL + b_{10}WB + b_{11}WC + b_{12}LB + b_{13}LC + b_{14}BC$$

where Q is the quantity supplied of the product, W is the price of wool, L is the price of sheep meat, B is the price of beef and C is the price of cereals. (Note the prices B and C differ from the points B and C in Figure 1).

Table 2: Range of Prices Used: 1982-83 Dollars

	Wool	Sheep meat	Beef	Cereals
	c/kg	c/kg	c/kg	\$/t
Experimental prices: level 1	175	80	50	32
2	235	105	95	76
3	295	130	140	120
4	355	155	185	164
5	415	180	230	208
Standard deviation (10 years)	60	25	45	44

Level 3 prices were those prevailing in 1982-83. Other price levels are one and two standard deviation units from level 3.

Results

The estimated supply functions are shown in the Appendix. Since the observations on the variables are deterministic from a descriptive point of view, the regression model does not conform to the usual assumptions of the general linear model.[2] The non-stochasticity makes the t values meaningless, but the coefficient of determination (R^2), is presented in the Appendix because it does give an indication of goodness of fit of the estimated function to the data (see Candler and Cartwright 1969).

[2] The linear programming solutions are not free of an error component, however. This arises from the uncertainty surrounding the programming model coefficients.

The supply functions estimated by ordinary least squares (OLS) were used to calculate point supply-response elasticities with respect to the four commodity prices, each at the level 3 prices in the experiment. The quantity of each commodity used in calculating the elasticity was that obtained by substituting the level 3 prices into the relevant equation of Appendix Table A1. The elasticities calculated are presented in Table 3.

The Wicks and Dillon estimates are based on a programming model, as discussed above, while the other estimates are based on econometric models.

The estimated elasticity of wool production, with respect to wool price is greater than that estimated by other studies. The concept of the supply elasticity of beef production is confused by the structural changes in the beef herd which determines its output response. Thus, within one season, the response to an increase in beef price will most probably be negative, as producers retain more breeding cattle and possibly hold fattening cattle back to heavier weights. In the programming models, this is not a problem as the elasticities are derived by comparing equilibrium output at one level of price with that at another level of price abstracting from the time path of adjustment. Simple econometric models cannot easily handle those structural changes. Vincent *et al.* (1980) estimated a one-year response elasticity of 0.59 which includes inventory change in its definition of production. The RPM figure of 1.34 is somewhat higher than the Wicks and Dillon intermediate run estimate of 0.90.

Table 3: *Medium-term Supply Response Elasticities Estimated with the RPM*

Item	Prices			
	Wool	Sheep meat	Beef	Cereals
Wool	2.02	0.34	−0.80	−0.52
Sheep meat	1.07	1.04	−0.62	−0.41
Beef	−0.69	−0.27	1.34	−0.04
Cereals	−0.45	0.01	0.02	0.59

Calculated at the appropriate level 3 price from Table 2. The corresponding quantities are wool 661 Kt, sheep meat 590 Kt, beef 1201 Kt and cereals 24 Mt.

These elasticities differ for two major reasons from those presented in the original RPM report by Longmire *et al.* (1979). First, the RPM model has been substantially revised and updated and all flexibility constraints have been removed. Second, the Longmire *et al.* estimates were based on linear regression functions which fitted the data less well than the quadratic, and finally, the elasticities are estimated at different price (and quantity) levels.

The calculated elasticities can be compared to a number of other estimates of own-price supply elasticities for Australia presented in Table 4. The corresponding 'length of run' is that stated in each paper.

Table 4: *Own-price Supply Elasticity Estimates: Australia*

Source	Period	Wool	Beef	Cereals *a*
This paper	intermediate term	2.02	1.34	0.59
Wicks and Dillon	short term	0.25	0.67	1.10
Wicks and Dillon	intermediate term	0.36	0.90	1.26
Powell and Gruen	5 years	0.33	*na*	0.85
Powell and Gruen	1 year	0.07	0.16	0.18
Malecky	5 years	0.35	*na*	*na*
Vincent, *et al.*	1 year	0.18	0.59	0.76
BAE (1976*b*)	5 years	*na*	*na*	0.25

a Wheat only for all except first and last study listed.

The supply-elasticity responses for cereals can be classed into two groups. The elasticity presented in this paper (0.59) represents the response of all cereals to changes in the price of all cereals, as does the BAE (1976*b*) projection. The other studies reported all calculated the response of wheat production to changes in the price of wheat, holding other cereal prices constant. Since wheat production is a close substitute for the production of other grains, the wheat-only elasticities are naturally higher than those of all cereals.

Intermediate-term cross-price elasticities for comparison with those from the RPM are available only from Wicks and Dillon. The estimates from these two sources corresponded reasonably closely — the supply elasticity of beef with respect to wool price was −0.69 for the RPM and −0.51 for Wicks and Dillon. For wool with respect to beef price the corresponding estimates were −0.80 and −0.25.

Discussion

The signs of the own-price elasticities are all positive, as would be expected. The estimated wool own-price elasticity is higher than that found by other studies with similar five year or intermediate adjustment periods. For beef, there is only one 'comparable' estimate which is that of Wicks and Dillon for the intermediate term. Here the estimates are reasonably close together, with the RPM estimate being somewhat higher. One possible explanation for the higher elasticity estimates in the RPM is that no arbitrary upper limits on output were imposed (*c.f.* 30 per cent maximum change limits in Wicks and Dillon). For cereals, the own-price elasticity is expected to be less than the elasticity for wheat only. The RPM elasticity estimate for cereals is in fact less than the five year or intermediate term wheat estimates of Wicks and Dillon, or Powell and Gruen.

For the cross-price elasticities, the strongest *a priori* expectation is probably that wool and sheep meat would be complements (i.e. have a positive sign). The RPM results confirm this. There is less basis for strong *a priori* expectations about whether other commodities complement or substitute for each other in production. The RPM results indicate that all other commodities are, in fact, substitutes, with the exception of the elasticity of supply of cereals with respect to changes in meat (both sheep and beef) price, where the coefficients are close to zero. The only other study reporting 'comparable' cross-price estimates was that of Wicks and Dillon. The signs of their estimates were the same and the magnitudes were similar to those reported in this study.

A referee of a previous version of the paper pointed out that the homogeneity assumption does not hold in the summary regression equations. (The sum of the own- and cross-price elasticities in Table 2 is not zero). However, the experimental procedure which underlies the elasticity calculations was to vary *output* prices only. An increase in all output prices with input prices unchanged would be expected to *increase* output. That is, the sum of the own- and cross-price elasticities would be expected to exceed zero, which in fact it does for all four commodities.

Conclusions

In this paper the aim was to present national supply elasticities with respect to product prices estimated with the Regional Programming Model. These elasticities have been compared to those from a similar model (APMAA) and other studies. The most interesting and relevant comparison was with the APMAA results which had a similar length of run. The elasticities calculated are presented here as a contribution to knowledge about the supply response of Australian agriculture in the intermediate term.

Appendix

Estimated Supply Functions

The quadratic supply functions estimated from the experimental data are presented in Table A1.

Table A1: Supply Functions Estimated

Price Variables	Quantities			
	Wool (kg)	Beef (kg)	Sheep meat (kg)	Cereals (t)
W	1.16359E7	7.52090E6	1.18684E7	6.98992E4
W^2	1.25390E3	−1.70625E4	−1.00542E4	−2.90164E2
L	5.26246E6	4.99727E6	1.78421E7	1.26162E5
L^2	1.04226E4	−3.62799E4	−9.11240E3	−6.11347E2
B	−3.03507E6	2.13431E7	−1.29509E6	4.36812E4
B^2	7.90820E3	−3.68765E4	1.50488E2	−2.07206E2
C	2.36959E5	−2.83699E6	2.70298E6	3.02450E5
C^2	2.07330E4	1.33011E3	7.58251E3	−1.24979E3
WL	−2.62232E4	−5.03349E1	−1.90523E4	2.53361E2
WB	−1.81333E4	1.87017E3	−4.14941E3	1.82425E2
WC	−1.59318E4	−4.45721E3	−6.21579E3	4.85051E1
LB	2.56310E4	−5.48845E3	−3.48588E3	−6.15594E2
LC	−1.75590E4	2.05837E4	−3.88321E4	3.83588E2
BC	−7.67168E3	5.31162E3	2.47965E3	3.70933E2
Constant	−1.54311E9	−1.74127E9	−2.70724E9	−1.77687E7
R^2	0.95	0.93	0.93	0.89

Note: *W* is price of wool (c/kg).
L is price of sheep meat (c/kg).
B is price of beef (c/kg).
C is price of cereals ($/t).

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