SUPPLY RESPONSE IN THE AUSTRALIAN SHEEP INDUSTRY: A CASE FOR DISAGGREGATION AND DYNAMICS*

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Microeconomic capital goods theory was utilised to provide a theoretical framework on which a dynamic econometric model was based. Econometric procedures were then employed in an analysis of sheep producers' decision making regarding the annual supplies of wool, lamb and mutton, and annual changes in the inventory levels of sheep, lambs and ewes maintained for breeding purposes. Estimates show that wool prices provide the long-run stimulus for increases and decreases in the sheep flock while mutton and lamb prices are responsible for short-run changes in flock composition. Substitution between sheep and beef cattle is of considerable importance although no significant substitution between sheep and cropping could be found. Seasonal conditions proved to be an important short-run supply shifter, affecting both numbers and composition of the sheep flock.

Introduction

This study focuses on annual production and inventory decisions of Australian sheep producers by modelling producer behaviour in the context of capital theory. The central theme of the paper is simple. Sheep are considered to be capital goods and producers are viewed as portfolio managers. In any period the producer of a good is faced with the problem of maximising some objective function (profit, utility) given some level of input costs, an anticipated output price and an initial stock of capital (fixed productive resources).

In the livestock sector there are factors other than prices that impinge upon production; e.g. seasonal conditions and biological constraints on output. Thus, any model which purports to explain a production decision within the livestock sector must explicitly account for all three elements of that decision; i.e. the demographic constraint, the economic decision and the modification of the decision caused by exogenous influences. The model outlined in this paper is intended to account for each of these elements in a logical and sequential way.

Two features of the hypothesised environment for producer decisions are highlighted. First, industry supply response must be disaggregated into its component parts. Within the general framework of investment decisions, it is necessary to differentiate between inventory and production responses and, because we are concerned with a multi-output industry, it is also necessary to disaggregate the production responses between wool, mutton and lamb. Second, the dynamic interrelationships of decision making need to be explicitly taken into account. The sequential nature of decisions within any one production planning period can be

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modelled through recursive relationships, while the effects of current-period decisions in determining future-period options and responses require the use of a dynamic simulation framework.

The concept of an analysis of supply response based on capital investment analysis is not new. Nor is the idea of demographic linkages. Indeed, the basic concept of the incompatibility of both output and investment for Australian agriculture was recognised by Gutman (1955), although no attempt was made to formalise the relationship. This pattern of behaviour by livestock producers is commonly recognised in discussions of industry outlook but has been generally ignored in the specification of econometric relationships of livestock supply. The basic demographic identity has been recognised but it has been used purely in a static way, no allowance being made for dynamic components in that relationship. The linkages in the economic environment for Australian sheep producers have not been fully spelt out, and econometric analysis using a model which incorporates these linkages is yet to be undertaken.

A sheep industry model is proposed to redress such problems as well as to open up what are believed to be potentially stimulating areas for future supply response studies.

Economic Theory of Capital and Investment

The basic microeconomic theory of capital and investment can be traced to Fisher (1907) and more recently to Hicks (1946) and Jorgenson (1963). More details of the investment decision model which underlies the specified supply relations are provided in earlier applications of the theory to livestock supply studies by Jarvis (1967, 1974), Court (1967) and Freebairn (1973). In this exposition only the basic theoretical core is presented, and concentration is directed to the behavioural postulates embodied in the theory.

The theoretical implications of intertemporal decision making by a firm are detailed in Henderson and Quandt (1971). From these it may be concluded that a movement in revenue in favour of one output, *ceteris paribus,* will lead to an investment in the means of producing that output and a disinvestment in the means of producing competitive outputs. This will continue until the prices of the various capital goods adjust to equate the internal rate of return and interest rates. For simplicity of exposition it is assumed that asset fixity precludes the possibility of converting agricultural land into alternative non-agricultural uses. Thus, the decision framework is limited to what types of agricultural production to pursue on any given area of land. There is little empirical evidence to suggest that, in aggregate, Australian farmers consider off-farm investment as an alternative to agricultural production.

In applying this theory to livestock, it must also be recognised that output can be increased only by increasing the size of the breeding flock and/or withholding stock for further production; i.e. the source of higher future production is an increase in capital stock. Further, sheep are different from manufacturing machinery in that female stock have a multi-product output in the form of lambs, meat and wool production. Although all livestock have multiple economic roles in the production process, sheep are more complex than cattle because of the need to consider wool as well as meat outputs.

As output prices rise, it pays to keep all animals longer; i.e. the optimal slaughter age increases. In the aggregate there will be a decrease in slaughter of all animals; a negative short-run slaughter response. As output prices rise, the opportunity cost of pasture land rises and, because of different discounting horizons, some animals become more valuable as capital goods relative to others.

Consequently, the decrease in slaughter of breeding ewes and lambs will be greater than that for wethers. Nevertheless, the slaughter response to output prices will be negative for each stock category in the short run (month, quarter), but must become positive for some longer run adjustment period.

The apparent 'perversity' of short-run supply response in the livestock industries is thus postulated to be a necessary, logical and distinctive feature. This is because current production decisions do directly affect future production capacity; i.e. current slaughterings reduce future inventory and hence future slaughter potential. As rational economic decision makers, sheep producers are assumed to be aware of this dichotomy and to consider the dynamic interrelationships during their decision making.

From the theory, a number of *a priori* hypotheses can be postulated. The short-term response to increasing output prices should be positive for wool supply and negative for mutton and lamb supply. This is because the higher prices extend the optimal productive life of the unit of biological capital. The long-term response will be positive although the time taken to establish this response is indeterminate. However, so long as the internal rate of return is greater than that from any other alternative enterprises, and there is excess capacity in the grazing industry, the short-run response will be negative as farmers expand their productive capacity.

Investment response with respect to increases in revenue from competing products can be positive or negative depending on the time allowed for adjustment. Enterprises compete for limited inputs and, as the rates of product transformation must be set equal to the inverse ratio of product prices, an increase in one set of output prices, *ceteris paribus,* will result in a reduction in the level of inputs into competing products. This leads to disinvestment in the less profitable capital goods and, if these are sheep, then disinvestment is characterised by increased slaughterings and reduced wool production. In the very long run, the impact of a rise in price for a competing product on the output from the sheep enterprise will be negative, but again the time path for the change is indeterminate.

Sheep supply response is seen as being crudely cobweb in nature. This arises through the biologically imposed discrete nature of production decisions within a framework of stochastic prices and climatic conditions. Thus, producers try to adjust production to meet desired end-of-year inventory levels for each stock category. This condition will be referred to as equilibrium. The coincidence of equilibrium and the actual outcome reflects the accuracy of producer forecasts of price and seasonal factors. If price and seasonal shifts are truly stochastic, and producers respond consistently to each new set of price signals, equilibrium will be achieved only by chance. Oscillations of actual production around long-term trends are seen as indicative of this, with production levels

consistent with the long-term trend sometimes attained, but not maintained.

A Dynamic Model of Producers' Decision Making

In any period, producers must make the choice between current production and future output, namely investment. For producers in aggregate, simultaneous decisions to invest in capital stock (to build up sheep numbers) and to increase current output cannot normally be taken. Producers must consider the future as well as the immediate effects of their decision. Slaughter and shearing are modelled as behavioural relationships while end-of-period inventory is found in an accounting manner by the consideration of opening inventories, net natural increase and slaughter. Consequently, the final inventory of livestock is dependent upon production decisions already made. The inclusion of separate equations for both production and inventory, e.g. by Freebairn (1973), is basically inconsistent with the dynamic nature of the decision environment.

It is necessary to disaggregate capital stock into homogeneous components since it is postulated that supply response may differ for each stock category. Such an approach is consistent with results of empirical studies of short-run beef supply response (see Reutlinger 1966), which clearly show differences with both sex and age of the animal. Further, it is desirable for model completeness that, subject to data limitations, separate behaviour functions of the investment decisions for each of the main turn-off categories (male, female and lamb slaughter and shearings) be considered.

It is postulated that the components making up the investment decisions (slaughter, births, deaths) should be modelled as behavioural relationships and inventory response be considered as a basic stock accounting identity. The demographic relationship outlining inventory response is thus led by and dependent on the investment decisions. The model consists basically of five component parts — three systems of behavioural equations which spell out inventory changes, turn-offs and per unit production, and two systems of identities which give closing sheep numbers and total production of each output for the year, the values for the latter being given by the solution of the former.

Figure 1 presents a summary of the hypothesised manner in which the investment and production decisions faced by sheep producers are interrelated. The linkages in time are delineated. Allowance for exogenous effects (live sheep exports) completes the system and allows the model to be solved in a dynamic simulation framework. The approach adopted is similar to studies of the Argentine cattle sector by Jarvis (1967, 1974), Yver (1971) and Nores (1972).

All output and investment decisions are hypothesised to be influenced by two differing sets of determinants. The first of these is the existing capital stock which sets the limits to adjustment and so determines the longer run equilibrium production responses. The second is changes in economic variables such as output prices and costs of production which, with allowances for seasonal conditions, determine shorter run responses around the equilibrium position. Thus the behavioural output-investment models have a relatively constant and a transitory compo-

nent, or alternatively, an equilibrium and a change from equilibrium component.

It is assumed that prices are determined exogenously and current supply is treated as an identity consisting of unit turn-off rates multiplied by stock utilisation quantities. The sequential nature of the relationships allows the models to be estimated recursively while still maintaining the dynamic linkages through a demographic identity.

Because the opening inventory of stock in each year is determined as an accounting identity of turn-off variables in the previous year, the model can be viewed as a partial stock adjustment scheme. Given current estimates of different output prices, producers then adjust turn-off variables to obtain their new perceived equilibrium stock level. Once such decisions have been made, producers are assumed to be locked into a pattern of turn-off for the current period. However, production or output may vary as a result of changes in average carcass weight or wool cut per head. Nevertheless, as it is highly unlikely that last period's sheep numbers are at the actual equilibrium level and that everything is 'normal' during the year, it is also highly unlikely that closing numbers will be the actual desired equilibrium level. Thus, the intertemporal adjustment may be only partial due to the lack of perfect forecasts and full information.

The important products of sheep farms are wool and sheep and lambs for slaughter. Additionally, inventory change occurs as lambs marked but not slaughtered are retained, and as sheep die. Stock utilisation (slaughter and shearing) is seen to be the means by which producers seek to maximise some time stream of discounted profits. Stock turn-off decisions are responsive to economic and seasonal factors but are limited by available capital stock. The relevant exogenous variables that impinge upon each of the stochastic equations embody economic responses through which exogenous shocks modify decisions. However, while there

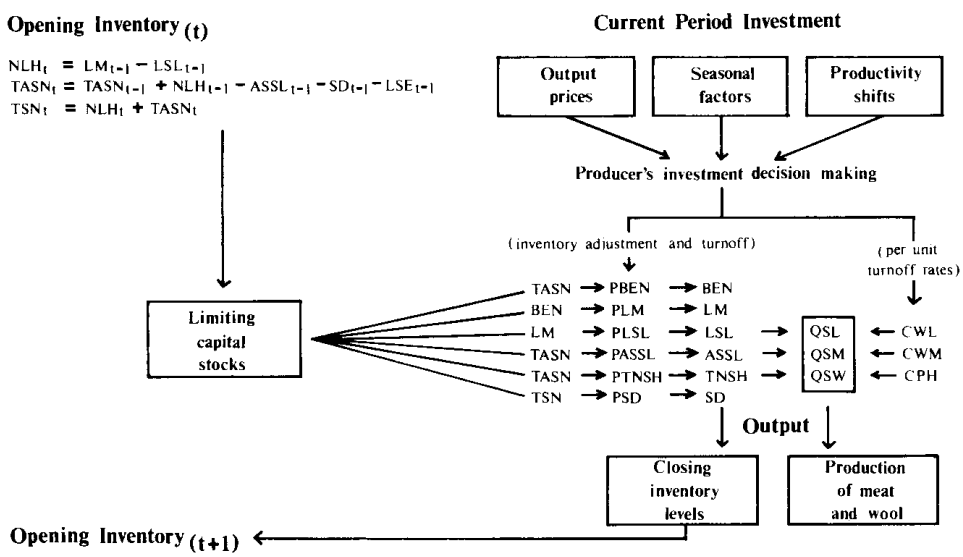

FIGURE 1—A framework for inventory and production relationships in the Australian sheep industry. (Variables are defined in the text.)

exist both biological and technical restraints on production, some minimum rate of utilisation (expressed as a percentage of opening numbers) is likely to occur.

Production may then be represented as a series of identities. Production levels of mutton and lamb are simply the product of sheep or lamb slaughter and respective average carcass weights. Wool production is obtained in a similar manner by multiplying numbers shorn and average wool cut.

The econometric sheep supply model was estimated using OLS regression with annual data for the period 1949/50 to 1977/78 inclusive. Beef, lamb and mutton prices are weighted average Australian saleyard prices. The seasonal index was formed using annual regional rainfall data weighted by sheep numbers in each region.

Prices in the current period only were included as explanatory variables on the assumption that this provided the best approximation of producer price expectations. Lagged prices were accounted for only to the extent that they influenced opening inventories. For the purposes of this model, current prices were considered as exogenous. This problem will be overcome when, with further development, the demand side has been formulated and the model can be estimated within a simultaneous framework.

Risk aversion was considered as a possible element in producer decision making. However, this variable was discarded as a price variance measure appeared to make no worthwhile statistical contribution.

Published slaughtering statistics for sheep are not disaggregated, so it was necessary to consider adults as a group. Mortality and lamb marking data are available and so were incorporated. Because lamb markings are principally determined by ewes mated, the number of ewes in the flock used for breeding purposes has been modelled as a behavioural relationship. It is hypothesised that producers view this decision like any other production/investment decision. All decisions are made within the limits of existing numbers, and in response to changes in seasonal conditions and economic factors.

Being a multi-product decision environment, sheep producers respond to changes in the prices of mutton, lamb and wool. Products are competitive with each other (e.g. slaughter negates wool production), but sheep held to the end of their productive lives still retain a salvage value in the form of the mutton returns. Because sheep are produced under extensive grazing conditions, the industry is competitive to some extent with both cattle and wheat production and thus sheep producers also respond to changes in beef and wheat prices. Consequently, it can be argued that prices of wool, mutton, lamb, wheat and beef should be included as explanatory variables in each behavioural equation. However, the saleyard price series are highly collinear, and this led to difficulties in model specification.

Pasture forage availability is relevant to decisions by producers to invest or disinvest in capital stock. In aggregate, it is assumed that there is no effective constraint from the pasture base on increase in inventories. However, should pasture availability be limiting, slaughtering may need to be increased above the desired levels. This would be achieved by the increase slaughter of male and older animals rather than increasing slaughter of females and younger sheep. The effect of the

pasture constraint was allowed for in the model by the 'area of pasture' variable.

Not only actual area but also the quality of pasture is important since in good seasons there is less pressure to slaughter, and animals may be retained for longer periods. The seasonal index, based on annual rainfall, was used in the model to capture this effect. However, the seasonal index is highly collinear with pasture availability since marginal land may be utilised in good seasons, and it was necessary to omit the pasture availability variable.

Results

The sheep supply model is made up of the following equations in which numbers in parentheses are t statistics for null hypotheses that respective coefficients are zero.

Opening livestock identities

(1) $TNLH_t = LM_{t-1} - LSL_{t-1}$

(2) $TASN_t = TASN_{t-1} + TNLH_{t-1} - ASSL_{t-1} - LSEX_{t-1} - SD_{t-1}$

(3) $TSN = TNLH_t + TASN_t$

Inventory adjustment behavioural models

(4) $$PBEN = \underset{(24.2)}{39.6} + \underset{(0.9)}{0.004SI_t} + \underset{(2.2)}{0.018PW_t} - \underset{(2.0)}{0.13PM_t} + \underset{(3.7)}{0.088PB_t} + \underset{(1.8)}{0.06PL_t}$$

$R^2 = 0.41 \quad DW = 1.75 \quad SE = 0.11$

(5) $$PLM_t = \underset{(16.3)}{47.5} + \underset{(7.3)}{0.085SI_t} + \underset{(3.6)}{0.29PL_t} - \underset{(3.0)}{0.34PM_t}$$

$R^2 = 0.66 \quad DW = 2.39 \quad SE = 0.027$

(6) $$PSD_t = \underset{(4.8)}{5.5} - \underset{(6.0)}{0.026SI_t} + \underset{(2.7)}{0.039PB_t} + \underset{(3.0)}{0.016PW_t}$$

$R^2 = 0.71 \quad DW = 1.83 \quad SE = 0.011$

Turn-off behavioural models

(7) $$PLSL_t = \underset{(5.7)}{21.4} - \underset{(1.7)}{0.026SI_t} + \underset{(1.7)}{0.17PL_t} - \underset{(2.7)}{0.44PM_t} + \underset{(6.5)}{0.37PB_t}$$

$R^2 = 0.61 \quad DW = 1.99 \quad SE = 0.034$

(8) $$PASSL_t = \underset{(9.2)}{9.8} - \underset{(0.9)}{0.005SI_t} - \underset{(4.8)}{0.19PM_t} + \underset{(6.2)}{0.144PB_t}$$

$R^2 = 0.60 \quad DW = 1.54 \quad SE = 138$

(9) $$PTNSH_t = \underset{(34.6)}{111.0} + \underset{(4.4)}{0.05SI_t} - \underset{(1.8)}{0.04PW_t} - \underset{(1.2)}{0.14PM_t} - \underset{(3.2)}{0.19PB_t}$$

$R^2 = 0.55 \quad DW = 2.40 \quad SE = 0.028$

Per unit production rate behavioural models

(10) $$CWL_t = \underset{(33.4)}{14.71} + \underset{(1.23)}{0.002SI_t} + \underset{(1.03)}{0.009PL_t} + \underset{(2.8)}{0.034TREND}$$

$R^2 = 0.39 \quad DW = 2.12 \quad SE = 0.055$

$$(11)\quad CWS_t = \underset{(45.8)}{19.4} + \underset{(2.6)}{0.006SI_t} - \underset{(1.7)}{0.016PB_t} + \underset{(1.0)}{0.015PM_t}$$
$$R^2 = 0.16 \qquad DW = 1.92 \qquad SE = 0.055$$
$$(12)\quad CPH_t = \underset{(33.5)}{3.72} + \underset{(4.1)}{0.002SI_t} + \underset{(6.5)}{0.023TREND} + \underset{(2.1)}{0.004PB_t}$$
$$R^2 = 0.70 \qquad DW = 1.96 \qquad SE = 1.102$$

Production identities

$$(13)\quad BEN_t = (PBEN_t/100)TSN_t$$
$$(14)\quad LM_t = (PLM_t/100)BEN_t$$
$$(15)\quad SD_t = (PSD_t/100)TSN_t$$
$$(16)\quad LSL_t = (PLSL_t/100)LM_t$$
$$(17)\quad ASSL_t = (PASSL_t/100)TSN_t$$
$$(18)\quad TNSH_t = (PTNSH/100)TSN_t$$
$$(19)\quad QSL_t = CWL_t \times LSL_t$$
$$(20)\quad QSM_t = CWS_t \times ASSL_t$$
$$(21)\quad QSW_t = CPH_t \times TNSH_t$$

where:

TNLH = the number of lambs and hoggets (1 year) in opening inventory (million),
TASN = the number of adult sheep in opening inventory (million),
TSN = the total opening inventory of sheep and lambs (million),
BEN = the number of ewes in the flock used for breeding purposes (million),
PBEN = *BEN* as a percentage of *TSN*,
LM = the number of lambs marked (million),
PLM = *LM* as a percentage of *BEN*,
SD = the number of sheep deaths (million),
PSD = *SD* as a percentage of *TSN*,
LSL = the number of lambs slaughtered (million),
PLSL = *LSL* as a percentage of *LM*,
ASSL = the number of adult sheep slaughtered (million),
PASSL = *ASSL* as a percentage of *TSN*,
TNSH = the number of sheep and lambs shorn (million),
PTNSH = *TNSH* as a percentage of *TSN*,
LSEX = the number of live sheep exported from Australia (million),
CWL = the average carcass weight of lambs slaughtered (kg),
CWS = the average carcass weight of adult sheep slaughtered (kg),
CPH = the average wool cut of sheep and lambs shorn (kg),
QSL = the quantity of lambs produced (kt),
QSM = the quantity of mutton produced (kt),
QSW = the quantity of wool produced (kt),
PB = the weighted average Australian saleyard price of cattle (c/kg),
PM = the weighted average Australian saleyard price of sheep (c/kg),
PL = the weighted average Australian saleyard price of lambs (c/kg),

PW = the average Australian auction price of greasy wool (c/kg),
SI = a seasonal index measuring rainfall (percentage of normal), and
$TREND$ = a time trend as a measure of technological change (1949/50 = 1, etc.).

The low R^2 statistics associated with most of the estimated equations do not detract from the model's usefulness for explanatory and predictive purposes. The dependent variables of the behavioural models are mainly expressed as proportions and the variance of such measures was small. Equations which explained even half of the variation of the proportion measures appeared satisfactory. When equations were estimated with numbers as dependent variables, more than 90 per cent of the variance was explained in most cases.

Discussion

Some of the signs in the estimated equations, particularly in the turn-off behavioural models, do not conform with those hypothesised. This can be attributed to some estimation problems arising from collinearity between the wool and mutton prices in particular, but also between these and the beef and lamb prices. Reverting to the theoretical basis and assuming zero salvage value, it can be shown that mutton prices are a good proxy for farmers' expectations of future wool and lamb prices net of costs of production. However, since this assumes zero salvage value, then mutton prices likely represent the lower limit of the sheep value.

Surprisingly, given that the bulk of the Australian sheep flock is bred for wool production, mutton price tends to dominate the wool price variable in most equations of the model. Because the coefficient for wool price tends to be of marginal statistical significance, mutton price variables have been retained while the wool price variable has sometimes been rejected as being insignificant. It was only in the breeding ewe and deaths equations that wool was statistically more important than mutton. That is, the importance of wool was in those equations most critical to longer run changes in the size of the flock.

Simulation experiments and sensitivity analysis with the model showed that the longer term structural responses were generally to changes in the price of wool. This result confirmed the hypothesis that wool price would provide the driving force for the sheep industry. Shorter term responses are accounted for mainly by seasonal conditions and meat prices; seasonal conditions were important through their impact on lambings and mortality, while meat prices picked up the substitution effect between sheep and beef.

Wool prices

Wool prices have their principal impact on breeding ewe numbers with an increase in the price of wool leading to an increase in the proportion of breeding ewes in the flock. Additional breeding ewes then produce additional lambs and thus higher sheep numbers in the following year. As would be expected, some of this impact is removed through higher sheep deaths. The positive coefficient on wool prices in the sheep deaths equation can be justified on the grounds of profit-maximising behaviour,

higher wool prices leading to an increased number of old sheep in the flock and increased grazing pressure.

Saleyard prices of sheep and lambs

The 'price of mutton' variable works sequentially through the system of equations. Higher mutton prices lead to lower proportions of breeding ewes in the flock, presumably as additional wether lambs are retained for future mutton production. Higher mutton prices are also associated with reduced lambing rates, lower rates of lamb and adult sheep slaughter and a higher proportion of numbers shorn. Mutton prices therefore appear to be a major factor in altering the composition of the adult sheep flock.

Rises in lamb prices lead to an increase in the proportion of breeding ewes in the flock, higher rates of lamb marking and higher rates of lamb slaughter. Higher lamb prices also lead to a slight increase in lamb carcass weights as producers hold lambs to heavier weights.

Saleyard prices of beef and wheat prices

The significance of the beef price variable gives some indication of the importance of substitution between sheep and beef cattle within the grazing industry. As beef prices rise, the rates of sheep deaths and sheep and lamb slaughterings rise, while the average carcass weight of sheep, wool cut per head and the proportion of numbers of sheep shorn fall. In this way beef prices influence both turn-off rates and per unit production within the sheep industry.

The positive coefficient on beef prices in the breeding ewe numbers equation implies that the proportion of breeding ewes in the flock increases as beef prices increase. This suggests a wool/beef substitution effect, with beef cattle being substituted for wool-producing animals, namely wethers. As the proportion of wethers in the flock declines, cut per head also declines. The negative coefficient on beef prices in the cut per head equation confirms this hypothesis. The hypothesis of risk aversion is also supported by producers retaining the breeding potential of their flock at the expense of nonbreeding animals. The proportion of breeding ewes in the flock rose from 44 to 49 per cent during the period 1964/65 to 1973/74, a period in which beef prices rose from 43c/kg to 79c/kg.

In comparison, the 'price of wheat' variable did not make a significant contribution statistically in any of the equations. Consequently, changing wheat prices are considered basically irrelevant to developments in the sheep sector. It is argued that, while wheat prices are relevant in the longer term as an indicator of profitability of cropping enterprises, wheat price shifts do not directly relate to changes in the livestock production enterprises on farms.

It is uncertain if this finding is a statistical phenomenon only, since the results are against published response studies. Nevertheless, because of the ley rotation practised on most Australian mixed farms, it is likely that producers make production choices between alternative livestock enterprises and, as separate decisions, between alternative cropping enterprises. A designated area of the farm is available for use of each enterprise, and this is fixed from year to year. Producers then seek to maximise revenue from each of the cropping and livestock enterprises

separately in response to individual product prices within each enterprise.

Seasonal conditions

Above-normal seasonal conditions lead to an expansion of the existing flock. The proportion of breeding ewes in the flock increases as non-breeding ewes are converted to breeding purposes; lamb marking rates increase due to higher conception rates and lower death rates between birth and marking; sheep deaths decline; the proportions of lambs and sheep slaughtered decline as a result of less pressure on pasture. As a result, numbers available for shearing increase. As well, carcass weights of sheep and lambs and cut per head are positively related to the seasonal index.

It has thus been shown that the model can be used to produce a more disaggregated and thus a clearer picture of supply responses in the sheep industry. The model is now used to identify wool, mutton and lamb supply parameters and the time paths of responses. The model has been used for medium term supply projections (BAE 1978) and was tested for predictive ability. A summary of these results is presented in the next section.

Ability of the Model to Predict

Figure 2 presents comparisons of predicted with actual levels of the total sheep numbers and production of wool, mutton and lamb. Predicted values were estimated by dynamic simulation for the period 1949/50 to 1977/78. Based on what is considered a severe test of the model's predictive ability, it was concluded that the sheep model satisfactorily depicted changes in supply through time. The model predicted the turning points and in most periods approximated well the actual levels of total production. Where divergence from actual values was observed, it was pleasing to note that the compounding of errors to future periods did not cause the model to 'explode' or to run down. Further, effects of errors could be traced through the system. This led to the conclusion that, although the demographic links and production responses in the sheep sector are various and complex, the model adequately represents the actual dynamic adjustment process.

Notably, the model did not exactly simulate the full extent of the magnitude of changes in total sheep numbers through time. This can be traced to a lack of price responsiveness in the sheep slaughter equation and the model's inability to capture the total impact of drought conditions in some years. However, the direction of change in all key supply variables was captured, and actual levels of these variables in the final years were predicted with great accuracy. Nevertheless, because the model failed to account for the full extent of liquidation of the flock in particular abnormal years (i.e. slaughter in 1971/72), this led to a general upward bias in the projections over the period. In periods of relative stability (the 1950s), the model predicted particularly well.

Theil U statistics (Intriligator 1978) were calculated on changes in the key projection variables over the period 1951/52 to 1977/78. Table 1 presents Theil statistics and a decomposition of projection error. Generally, the Theil statistics suggest that the supply model is a projec-

tion tool much superior to the naive no-change projection approach. Decomposing the source of projection error showed that the greatest portion of error may be ascribed to random components. Because the model does satisfactorily depict the main structural links underlying

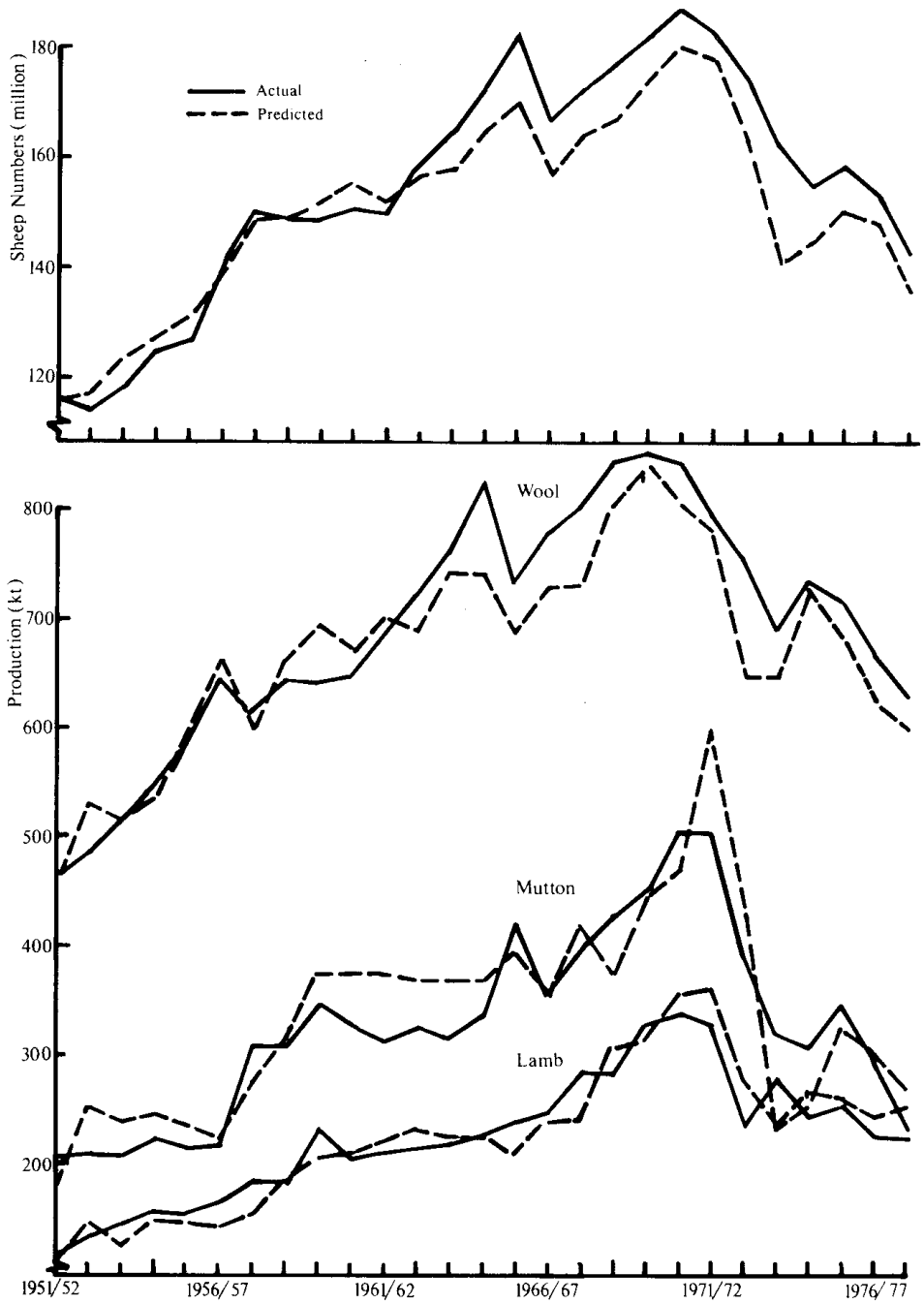

FIGURE 2—Actual and predicted levels of sheep numbers, wool production, mutton production and lamb production.

sheep supply response, it is possible to trace the effects of changes in exogenously determined variables.

TABLE 1

Theil Statistics and Decomposition of Projection Error

Changes in projected item	Theil *U* statistic	Source of error per cent		
		Bias	Slope	Residual
Total sheep numbers	0.30	2.1	2.2	95.7
Production of wool	0.21	0.3	10.6	89.1
Production of mutton	0.53	3.2	1.0	95.8
Production of lamb	0.35	0.1	3.6	96.3

Conclusion

Our objective was to estimate a model of supply which we believed to be applicable to the situation faced by Australian sheep farmers. Relationships for quantities of wool, mutton and lamb supplied and changes in inventory levels were postulated as describing Australian producers' responses to changing output prices and seasonal conditions. Analysis has yielded estimates of supply relations which are consistent with theory and contribute to the refinement of prediction. Improved understanding is possible of producers' short-run and long-run decision making as it determines the investments or disinvestments in sheep.

The proposed model then has a number of advantages over previously published work. Linkages between the various turn-off rates and the demographic identity have been clearly specified and fluctuations from normal described in economic and seasonal terms. Many agricultural economists who have estimated livestock supply functions have observed zero or negative elasticities of output with respect to the price of that output. Far from being 'perverse', this article has shown such responses by livestock producers to be logical. Explicit theoretical as well as empirical evidence has been presented to show that the short-run supply elasticity for wool, mutton and lamb may be zero or negative. However, the basic prerequisite to understanding livestock supply response was to disaggregate total inventory into homogeneous capital stock groupings, to differentiate inventory response from turn-off response and to incorporate directly the intertemporal nature of investment decisions.

However, some problems persist. There is a body of microeconomic theory which suggests that price responses of producers should be nonlinear in nature. The only condition necessary for this to apply is that the production function displays diminishing returns to scale, a common and realistic assumption for agriculture in general. It simply implies that the cost of saving an additional sheep or raising an additional lamb increases at an increasing rate until a point is reached when it is physically impossible to save sheep from dying, irrespective of price. That a linear model appears to work can be explained by the assumption that, over the range of the data, the response approximates linearity. Problems with assumptions of linearity are that no upper bounds are placed on predic-

tions and, relatedly, response is assumed symmetric for price rises and price falls. It is obvious that there are far greater restrictions to building up flocks in times of high price than to running down flocks in periods of low prices. A good example is the period 1971/72 to 1972/73 during which the accumulation in flock numbers over a period of 15 years was liquidated in the space of two years.

The treatment of prices as exogenous in this model is also recognised as a strong assumption. However, work has been proceeding within the BAE to develop a sheep meat demand model which, linked with this supply model, would permit the combined system to be estimated within a simultaneous framework. Once this is done, the next logical step would be to link in the important wool demand relationships and interactions of the sheep sector with the cattle and cropping sectors.

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