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Empirical investigation of investment behaviour in Australia's pastoral region*

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Optimal intertemporal investment behaviour of Australian pastoralists is modelled using panel data for the period 1979–1993. Results indicate that quasi-fixity of inputs of labour, capital, sheep numbers and cattle numbers is characteristic of production in the pastoral region. It takes about two years for labour, four years for capital and a little over two years for both sheep numbers and cattle numbers to adjust towards long-run optimal levels. Results also indicate that, after accounting for adjustment costs, own-price product supply and input demand responses are inelastic in both the short and long run.

Key words: adjustment costs, pastoralism, supply response.

1. Introduction

The supply response of Australia's agricultural industries has been a long-standing research interest (see e.g., Powell and Gruen 1967; McKay *et al*. 1980; Vincent *et al*. 1980; Fisher and Wall 1990; Kokic *et al*. 1993). These studies typically estimate the short-run and/or long-run own price elasticity of supply of commodities. However, these studies rarely address the time path or nature of change between the short and long run (Treadway 1970; Kulatilaka 1985; Wall and Fisher 1988). Yet adjustment costs associated with changes in inputs and outputs are known to be an important feature of agricultural decisions (Musgrave 1990; Gow and Stayner 1995). Given the central role of adjustment cost considerations in agricultural production decisions, a theoretically sound and empirically tractable framework is needed for the analysis of the effect of adjustment costs on product supply and input demand responses.

In addressing this issue several studies have used optimal intertemporal investment modelling to investigate dynamic adjustment behaviour of farmers (Taylor and Monson 1985; Vasavada and Chambers 1986; Howard and Shumway 1988; Vasavada and Ball 1988; Fernandez-Cornejo *et al*. 1992; Krasachat and Coelli 1995). This approach to examine a firm's production behaviour came to prominence following the seminal works of Eisner and Strotz (1963), Lucas (1967) and Gould (1968) and later

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added to by Treadway (1969, 1970), McLaren and Cooper (1980) and Epstein (1981). This approach is yet to be applied to Australian agriculture. Hence, a motivation for this paper is to investigate the responsiveness of Australian farmers to changes in output and input prices. The specific objective of the present study is to investigate the nature of farmers' investment behaviour in Australia's pastoral region using the optimal intertemporal investment modelling approach. Product supply functions for wool and wheat and input demand functions for materials and services, labour, capital, sheep numbers and cattle numbers are determined simultaneously within a generalised Leontief production technology framework. The iterative seemingly unrelated least squares technique is used to fit a dynamic model to Australian Bureau of Agricultural and Resource Economics (ABARE) panel data for the period 1979 through to 1993. The chosen period represents a turbulent time in Australian agricultural history, particularly for wool and livestock industries, and so the findings of this study could provide insights about structural responses of farmers in difficult times.

In the present paper, section 2 presents a system of equations depicting a farmer's optimal intertemporal investment behaviour. Data used to estimate this system of equations for Australia's pastoral industry are described. Then the model is used to test adjustment cost hypotheses of instantaneous and independent adjustment of quasi-fixed inputs of Australia's pastoral industry. These inputs are labour, capital, sheep numbers and cattle numbers. The final section contains the study's conclusions.

2. Methodological framework

2.1 Model specification

The farmer is assumed to maximise a stream of net cash flows over an infinite horizon at a given point in time subject to technological constraints. It is assumed that the levels of investment in quasi-fixed inputs affect the production function; that is, in the short run, firms cannot change the levels of quasi-fixed inputs without incurring costs. It is also assumed that the service flow of quasi-fixed inputs is proportional to their stock level. The production process is characterised by a transformation function, $f(X, K, I) = 0$, where X is a vector of variable inputs, K is a vector of quasi-fixed inputs, and I is a vector of gross investment in quasi-fixed inputs. The intertemporal profit maximisation problem of a farmer facing adjustment costs is expressed as:

$$V(p, w, q, k) = \max_{Y, X, K} \int_0^{\infty} e^{-rt}[p'\mathrm{Y} - w'\mathrm{X} - q'\mathrm{K}]\,dt \qquad (1)$$

subject to $\dot{K} = I - \delta K$, $K(0) = K0 > 0$, and $Y = f\ (X, K, I)$.

In Equation 1, $V(\cdot)$ stands for the value of the farmer's productive assets over an infinite time horizon, p is price vector of outputs produced, w is a price vector of variable inputs, q is a shadow price vector of quasi-fixed inputs; K is a vector of stocks of quasi-fixed inputs, I is a vector of physical investment in quasi-fixed inputs; r is the discount rate, δ is a diagonal matrix, the k-th component of which denotes the depreciation rate of the k-th stock of quasi-fixed input; $K0$ is an initial endowment of K, $\dot{K}$ is the net investment in quasi-fixed inputs; and Y is a vector of outputs.

In a dynamic agricultural setting, farmers typically restructure their resource allocation decision in response to changing relative prices of outputs and inputs. Price changes are induced by a variety of factors including, but not limited to, the influence of technical change. A technical change variable is included in Equation 1 to capture the impact of technology on output supplies and input demands. The inclusion of technical change provides a means for accounting explicitly for the technical interactions between activities within the rural sector and for maintaining consistency with the theoretical requirements of a value function (Martin and Alston 1994). Following previous Australian studies, the technical change variable is captured by a time trend variable.

Provided that the production function $f(\cdot)$ in Equation 1 satisfies regularity conditions, that is, the production function is finite, non-negative, real-valued, continuous, smooth, monotonic, twice continuously differentiable, bounded and strictly concave in K and I, then the value function in Equation 1 satisfies the Hamilton-Jacobi-Bellman (HJB) equation, which enables transformation of the static optimisation model in Equation 1 into a dynamic model. Allowing for technical change implies a nonautonomous dynamic optimisation problem. Following Luh and Stefanou (1991), the HJB equation corresponding to Equation 1 is:

$$r\,V(p, w, q, k, t) = \max_{I}[\pi^*(p, w, K, I, t) - q'K + V_K'(p, w, q, K, t)(I - \delta K)] + V_t(p, w, q, K, t), \tag{2}$$

where π^* is the short run optimal profit level and V_K is the derivative of V with respect to K and the other variables are as defined for Equation 1.

Assuming the integral of Equation 2 converges and regularity conditions are imposed on π, then the dynamic profit maximisation problem has a solution characterised by the HJB equation (Pietola and Myers 2000). Invoking Hotelling's Lemma, the derivative of Equation 2 with respect to input and output prices yields the conditional short run optimal investment demand, output supply and variable input demand equations. Differentiating Equation 2 with respect to q yields the optimal investment function:

$$\dot{K}_q = V_{kq}^{-1}(r\,V_q + K - V_{tq}). \tag{3}$$

Differentiating Equation 2 with respect to output price p yields the optimal supply function:

$$r\,V_p = -K + V_{kp}\dot{K} + V_{tk}, \tag{4}$$

and differentiating it with respect to variable input price w yields the optimal variable input demand function:

$$r\,V_w = -K + V_{kw}\dot{K} + V_{tk}. \tag{5}$$

Differentiating Equation 2, the optimised value function, with respect to K gives

$$r\,V_K = \pi_K - q - \delta V_K + V_{KK}\dot{K} + V_{tk}, \tag{6}$$

and rearranging terms yields

$$(r+\delta)V_K = \pi_K - q + \dot{V}_K, \tag{7}$$

where

$$\dot{V}_K = V_{KK}\dot{K} + V_{tK}. \tag{8}$$

Equation 8 states that the opportunity cost of investing in an additional unit of capital $(r+\delta)\ V_K$, equals the instantaneous gain in profit from an additional unit of capital, $\pi_K - q$, plus the instantaneous capital gain (or loss) of an additional unit of capital, $\dot{V}_K$.

Empirical implementation of the model requires a choice of functional form that satisfies all the regularity conditions. For $rV(\cdot)$, following Howard and Shumway (1988), the production technology is specified to be of Generalised Leontief (GL) form. The GL function is flexible and satisfies the regularity conditions of a value function; the GL model maintains the flexible accelerator investment properties that are essential for deriving the quasi-fixed input demand functions and for testing for quasi-fixity of inputs. The GL function also satisfies the HJB equation with properties of linear homogeneity in prices and concavity in quasi-fixed inputs. The model is specified as:

$$\begin{aligned} r\,V(p, w, q, K, t) = {} & [pw']\mathrm{A}K + q\mathrm{B}^{-1}K + [p^{0.5}w^{0.5}]\mathrm{E}q^{0.5} + [q^{0.5}\mathrm{F}q^{0.5}] \\ & + [p^{0.5}w^{0.5'}]\mathrm{G}[p^{0.5}w^{0.5'}]' + \mathrm{Z}[pw'q], \end{aligned} \tag{9}$$

where the variables are as defined above, and A and E are 3×4 matrices, G is a 3×3 matrix, B is a 4×4 matrix and Z is a 1×7 matrix of time trend variable.

Most studies of intertemporal profit-maximising behaviour assume farmers form expectations about price statically. A study by Thijssen (1996) assessed two specifications of expectation, the static expectation and rational expectation formulations. Thijssen's models were derived by maximising the expected present value of income over an infinite planning horizon, assuming a quadratic form of production technology. Thijssen concluded that the static expectation modelling provides an appropriate description of the decisions made by the farmers and the elasticity estimates are reasonable. By contrast, results based on rational expectations were found to be inconsistent with the theory when applied to microeconomic and aggregate data. The findings of Thijssen are consistent with the efficient market hypothesis proposed much earlier by Fama (1970). Fama argued that current price contains all relevant information about future price. As economic conditions change, farmers recognise the inherent cost of acquiring information and may formulate expectations rationally by continuously updating decisions based on readily accessible information, such that the expected price becomes equal to the current price. This study therefore assumes that farmers form expectations about price statically, that is, current price can be used as a proxy for expected price.

2.2 Data sources and description

The optimal intertemporal investment model is estimated for the period 1979–1993 using panel data obtained from farm surveys conducted by the Australian Bureau of

Agricultural and Resource Economics (ABARE). The study region chosen for this analysis is the Australian pastoral region which consists of six subregions as specified by ABARE. Seventy-five observations of aggregate panel data were used.

Variables in the model are price and quantity variables for inputs and outputs. Price variables are based on price indices for outputs, the variable input and other quasi-fixed inputs. Relevant price data came from the *Commodity Statistical Bulletin* 1994 (and earlier editions) (ABARE 1994). Output variables are wool output (total wool produced in kilo tonnes of greasy wool) and wheat output (total wheat produced in kilo tonnes). A single variable input, materials and services, includes expenditure on repairs, fodder, chemicals, insurance, electricity, fuel, rates and taxes and advisory services. Implicit quantity indices for materials and services are obtained by dividing expenditure on these items by an index of prices paid by farmers for materials and services.

Four quasi-fixed inputs are included; labour, capital, sheep numbers and cattle numbers. Labour is treated as a fixed input and is measured by the index of total number of weeks worked in a given year in the rural sector by hired labour, family labour and operator labour. It is important to note that the total labour force available for farm production depends on the quality of labour, which in turn is influenced by managerial abilities, technical skills and education levels (Powell 1974). However, no adjustment is made to account for labour quality differences in this study. Nonetheless, the technical change variable implicitly accounts for improvement in labour quality. The service flow from capital is assumed proportional to capital stock, which consists of depreciation, maintenance (included in the materials and services category) and capital gain. Capital gain of quasi-fixed inputs is treated as unrealised outputs, and is therefore not included in the derivation of capital stock (see Fisher and Wall 1990). An implicit quantity index for capital is derived by dividing capital expenditure by the index of prices paid by farmers for capital. Following Fisher and Wall (1990), the quantity of service flow of sheep and cattle inputs is measured as the total opening numbers on pastoral properties. A constant discount rate of 6 per cent is assumed. Dummy variables are included in the model to capture variations in production technology across regions.

2.3 Estimation method

The full empirical model comprises two outputs, one variable input and four quasi-fixed inputs. The estimated regression equations are appended with disturbance terms to reflect errors of optimising behaviour caused by unexplained changes in dependent variables. The error terms of each output supply and input demand response equation are assumed to be additive and satisfy the classical assumptions of Ordinary Least Squares (normally distributed with a zero population mean, constant variance and uncorrelated across and within equations). The maintained structural model is recursive in nature and the system of equations has been estimated by the iterative non-linear seemingly unrelated least squares (ISURE) procedure in SHAZAM Version 8.0 (described by White 1997). The Davidson-Fletcher-Powell algorithm is used to obtain the parameter estimates of the model. The estimation converged after 140 iterations. The ISURE parameter estimates are asymptotically equivalent to the Maximum Likelihood estimates at the point of convergence (Vasavada and Ball 1988).

3. Results and discussion

Table 1 reports parameter estimates and asymptotic *t*-statistics derived by the ISURE method. Nearly all the estimated parameters are asymptotically significant at a 10 per cent level. Parameter estimates of the dummy variables are not reported in this paper but are available from the authors. The goodness-of-fit measure of the dynamic model is a generalised measure proposed by Baxter and Cragg (1970) as, $\bar{R}^2 = 1 - \exp(2(L_0 - L_1)/N)$, where L_0 is the sample maximum of the log-likelihood

Table 1 Parameter estimates of the dynamic adjustment model for the pastoral region

Parameter	Estimate	*t*-ratio	Parameter	Estimate	*t*-ratio
A11	−2.199	−11.260	H3	−0.521	−0.976
A12	2.083	17.838	B11	−0.570	−7.535
A13	2.446	6.737	B12	0.026	0.711
A14	−3.213	−10.400	B13	0.105	1.221
E11	5.674	3.596	B14	0.168	2.216
E12	−7.258	−3.991	F11	9.707	4.829
E13	−13.611	−6.974	F_{12}	−10.215	−5.778
E14	−11.988	−5.151	F13	4.184	3.060
G11	24.206	11.173	F14	−15.128	−8.592
G12	−1.350	−0.683	F22	1.963	1.231
G13	6.866	5.604	F23	0.390	0.404
H1	−0.367	−2.272	F_{24}	−2.233	−1.185
A21	−1.563	−1.736	F_{33}	−6.115	−5.198
A22	2.576	3.861	F34	2.535	1.658
A23	2.651	2.102	F44	−15.375	−6.137
A24	−3.598	−3.323	H4	0.217	0.736
E21	−7.299	−3.498	H5	1.555	4.259
E22	1.966	1.739	H6	0.365	1.988
E23	−19.283	−6.535	H7	−0.644	−3.157
E24	20.658	8.907	B22	−0.342	−7.932
G22	5.566	3.924	B21	−0.092	−1.161
G23	−10.396	−5.890	B23	0.580	4.433
H2	2.376	3.351	B24	−0.411	−5.606
A31	2.619	6.875	B33	−0.536	−10.139
A32	−4.313	−21.104	B31	−0.085	−2.633
A33	−4.875	−6.450	B32	0.075	4.224
A34	5.804	11.062	B34	−0.169	−3.391
E31	−3.759	−2.269	B44	−0.513	−7.754
E32	0.534	0.503	B41	0.257	4.616
E33	4.659	1.739	B42	−0.164	−5.209
E34	15.380	8.615	B43	0.013	0.166
G33	−13.441	−4.252			

No. equations = 7; generalised R^2 value = 0.9940; no. parameters = 63; *D-W* statistic: wool = 2.044; wheat = 1.946; materials and services = 2.470; labour = 2.425; capital = 1.954; sheep numbers = 2.020; cattle numbers = 2.119.

ratio when all slope coefficients are zero, L_1 is the sample maximum of log-likelihood when all slope coefficients are unconstrained, and N is the total number of observations. The $\bar{R}^2$ coefficient of 0.9940 indicates that the dynamic model has a high level of explanatory power.

The hypotheses of homogeneity and concavity of the GL model were not tested because these assumptions are maintained by the GL form (Howard and Shumway 1988). The test for symmetry was not performed because symmetry in parameters has been imposed on the estimated model by constraining the appropriate cross-partial derivatives to be equal (Coxhead 1992). The test for convexity in prices of the value function follows the approach suggested by Howard and Shumway (1988). The calculated Chi-square value of 262.2 is greater than critical value of 32.67 (5% significance level, 21 d.f), hence the null hypothesis that the value function satisfies the convexity condition is rejected. Notably, specified models have failed the convexity condition in several other studies – including McKay *et al.* (1980, 1982) and Fisher and Wall (1990) in Australia, who used a similar data set but different functional forms, and Taylor and Monson (1985) and Krasachat and Coelli (1995) abroad – so this problem is not unique to the current study.

3.1 Rates of adjustment

The focus of this study is dynamic adjustment in agricultural production in the pastoral region, so tests were performed for independent adjustment and instantaneous adjustment of quasi-fixed inputs of labour, capital, sheep numbers and cattle numbers. Following Howard and Shumway (1988), 'independence of adjustment occurs when $M_{ij} = M_{ji} = 0$, and means that each quasi-fixed input adjusts toward its desired level independently of the other' (p. 842), where i and j denote quasi-fixed inputs (where $i, j = 1, \ldots, 4$, for labour, capital, sheep numbers and cattle numbers, and where i^1 j). Likelihood ratio tests were performed to test the hypotheses of independent

Table 2 Sequential hypothesis tests for instantaneous and independent rates of adjustment of input levels

Hypothesis	Test statistic
*Instantaneous adjustment**	
Labour	347.64
Capital	1041.24
Sheep	397.43
Cattle	301.13
Independent adjustment†	
Labour and capital	7.27
Labour and sheep	5.25
Labour and cattle	37.95
Capital and sheep	86.30
Capital and cattle	24.92
Sheep and cattle	5.23

*Critical value at a 5 per cent level of significance and 4 d.f. is 9.49. †Critical value at a 5 per cent level of significance and 2 d.f. is 5.99.

adjustment and instantaneous adjustment. Table 2 reports tests for independent adjustment of quasi-fixed inputs. With the exception of labour-sheep and cattle-sheep input pairs, the calculated likelihood ratio statistics exceed the critical value of 5.99 (5% significance level, 2 d.f). The results indicate that, with the exception of the labour-sheep and cattle-sheep input pairs, all input pairs adjust independently.

The finding that labour and sheep adjust jointly is consistent with agricultural production in the pastoral region. In the pastoral region, a large proportion of labour is used in the sheep industry for animal handling (e.g., shearing), hence it would be expected that investment decisions about labour and sheep numbers would be made jointly. Further, the finding that investment decisions about sheep flock and cattle herd inventories are made jointly is not surprising, given the dominance of these enterprises in the pastoral region and their joint dependence on rangeland condition. This finding implies that sheep and cattle supply response in the pastoral region should be modelled jointly.

A test is performed to find instantaneous adjustment of quasi-fixed inputs. Following Howard and Shumway (1988), 'if $M_{ii} = -1$ and $M_{ij} = 0$, the i-th quasi-fixed input adjusts instantaneously to its desired level and should be modelled as a variable input' (p. 842). The test is performed with the assumption of independence maintained and test results are listed in Table 2. In all cases, the null hypothesis of instantaneous adjustment is rejected at the 5 per cent significance level for quasi-fixed inputs of labour, capital, sheep numbers and cattle numbers, given that the calculated likelihood ratio statistics exceed the critical value of 9.49 for 4 d.f. It is concluded that these quasi-fixed inputs do not adjust instantaneously (more precisely, within one year) towards their long-run optimal levels. In other words, these quasi-fixed inputs sluggishly adjust, suggesting that asset fixity is characteristic of agricultural production in Australia's pastoral region.

The estimated adjustment rates of the quasi-fixed inputs of the accepted model provide information on the relative speed of adjustment of these inputs towards their long run equilibrium levels. The stability of the adjustment process is determined by examining the eigenvalues of the adjustment matrix. The real parts of the estimated eigenvalues are negative and less than unity, implying that the adjustment matrix and the estimated system are stable, thus confirming the general assertion that quasi-fixed inputs adjust to their long-run optimal levels. The estimated adjustment rates are −0.51 for labour, −0.28 for capital, −0.47 for sheep numbers and −0.45 for cattle numbers. This indicates that 51 per cent of the optimal net investment in labour will occur in the first year in response to changes in the relative price of other quasi-fixed inputs and outputs. Similarly, 28 per cent of the optimal net investment occurs in the first year for capital, 47 per cent for sheep numbers and 45 per cent for cattle numbers. The results also indicate that the full adjustment of labour takes approximately two years while that for capital takes approximately four years. For sheep and cattle numbers, full adjustment occurs a little over two years.

The estimated adjustment rates of quasi-fixed inputs reported in this study can be compared to those in earlier studies. The adjustment rate of labour (defined as family and hired labour) of 51 per cent a year reported in this study is higher than equivalent rates reported in several other studies. Chang and Stefanou (1988) reported an adjustment rate of labour of 21 per cent a year for Pennsylvania dairy producers and Stefanou *et al*. (1992) reported 38 per cent a year for pre- and post-quota years for Germany's milk producers. Also Krasachat and Coelli (1995) estimated the adjustment rate of labour to be 34 per cent a year for Thailand farmers and Howard and Shumway (1988) estimated 40 per cent a year for the USA dairy industry.

The adjustment rate of capital of 28 per cent a year reported in the present study is lower than the 81 per cent a year reported by Chang and Stefanou (1988) and the 55 per cent a year reported by Stefanou *et al*. (1992), but higher than 0.03 per cent reported by Krasachat and Coelli (1995) for Thai agriculture. For aggregate analysis, the adjustment rate of capital reported in this study falls within the range of 12 per cent a year reported by Vasavada and Chambers (1986) for USA agriculture and the 55 per cent a year reported for south-eastern USA agriculture by Taylor and Monson (1985). The adjustment rate of cattle numbers of 45 per cent a year reported in this study is greater that the 4 per cent a year reported by Howard and Shumway (1988) for cow numbers in the USA dairy industry.

3.2 Short-run and long-run optimal relationships

Tables 3 and 4 present the short and long-run own-price elasticities of output supply and input demand, respectively, for Australia's pastoral industry. The short run is the period within which there is no change in capital stock, while the long run assumes that the firm is operating at a long-run optimal level such that capital stock can be adjusted fully without incurring additional costs. All the own-price elasticities of output supply and input demands have the expected signs and show a general inelastic pattern in both the short and long run. The own-price elasticities of supply of wool and wheat have the

Table 3 Short-run elasticities of output supplies and input demands

	Quantity			Price			
	Wool	Wheat	Materials and services	Labour	Capital	Sheep meat	Beef
Wool	0.209	−0.172	0.279	0.093	−0.161	0.011	−0.241
	(4.03)[†]	(−2.34)	(6.75)	(2.54)	(−5.05)	(0.31)	(−6.12)
Wheat	−0.018	0.200	−0.267	−0.305	0.099	−0.180	0.472
	(−0.51)	(3.02)	(−5.79)	(−7.97)	(4.31)	(−5.04)	(9.83)
Materials and services	−0.155	0.081	0.060	−0.227	0.107	0.095	0.040
	(−6.25)	(2.43)	(0.97)	(−6.24)	(3.14)	(2.00)	(1.64)
Labour	−0.070	0.073	0.065	−0.404	0.140	−0.028	0.223
	(−3.70)	(1.54)	(3.75)	(−3.70)	(3.33)	(−0.94)	(5.93)
Capital	−0.013	−0.245	−0.037	0.235	−0.049	0.034	0.143
	(−0.54)	(−4.02)	(−1.44)	(2.40)	(−1.40)	(1.41)	(3.70)
Sheep	0.098	0.122	−0.068	−0.074	0.057	−0.119	−0.055
	(5.11)	(3.81)	(−2.47)	(−1.51)	(2.37)	(−5.06)	(−2.57)
Cattle	0.098	−0.196	−0.125	0.448	−0.105	−0.006	−0.115
	(4.52)	(−4.20)	(−5.59)	(5.31)	(−2.61)	(−0.19)	(−3.26)

[†]Values in parentheses are *t*-ratios.

Table 4 Long-run elasticities of output supplies and input demands

	Quantity			Price			
	Wool	Wheat	Materials and services	Labour	Capital	Sheep meat	Beef
Wool	0.275	−0.065	0.250	0.105	−0.120	−0.232	−0.198
	(4.83)†	(−0.80)	(5.60)	(3.50)	(−4.01)	(−6.67)	(−4.30)
Wheat	−0.032	0.285	−0.238	−0.097	0.035	−0.206	0.268
	(−0.83)	(3.72)	(−5.71)	(−2.35)	(2.47)	(−5.56)	(7.95)
Materials	−0.129	0.144	0.047	0.082	−0.001	−0.029	−0.104
and services	(−4.91)	(3.42)	(0.85)	(1.45)	(−0.08)	(−0.77)	(−3.19)
Labour	−0.073	0.081	0.068	−0.445	0.049	−0.036	0.248
	(−3.46)	(1.52)	(3.56)	(−3.64)	(0.56)	(−1.10)	(5.86)
Capital	−0.039	−0.332	−0.041	0.246	−0.205	0.166	0.116
	(−0.94)	(−4.11)	(−1.06)	(1.46)	(−1.48)	(3.06)	(1.55)
Sheep	0.099	0.115	−0.075	−0.085	0.019	−0.109	−0.007
	(4.23)	(2.46)	(−2.32)	(−1.18)	(0.36)	(−3.22)	(−0.21)
Cattle	0.121	−0.178	−0.138	0.476	−0.054	−0.028	−0.134
	(6.23)	(−3.32)	(−6.16)	(5.06)	(−0.96)	(−0.86)	(−4.05)

†Values in parentheses are *t*-ratios.

correct positive sign and increase over time. Short-run own-price supply elasticities are 0.209 for wool and 0.200 for wheat, increasing to 0.275 for wool and 0.285 for wheat in the long run. The positive sign of the own-price elasticities indicates that the supply functions are upward slopping in own price. Short and long-run own-price elasticities of demand for labour are all negative, estimated to be −0.404 and −0.445, respectively. This indicates that the labour demand functions are downward sloping in own price. The level of capital expenditure appears to be unresponsive to own-price in both the short and long run. This suggests that policies aimed at influencing the cost of capital would not be particularly effective in influencing the demand for capital in the pastoral region. The demand for materials and services also is unresponsive to own-price in the short and long run. However, the own-price elasticities of sheep numbers and cattle numbers are negative in both the short and long run.

Surprisingly, the response in sheep numbers to the price of sheep meat declines slightly in the long run, possibly reflecting the increasingly pessimistic woolgrower expectations about future prospects for Australian wool at the time. The Reserve Price Scheme for wool collapsed in 1991, unleashing acrimonious debate within the industry, and disposal of the wool stockpile took years. The results in Tables 4 and 5 indicate that although the price of sheep meat does not influence wool production in the short run, it becomes a statistically significant explanatory variable in influencing wool production in the long run. The long-run wool supply response to the price of sheep meat is negative, suggesting that wool and sheep meat are competitive products. This result indicates that, in the long run, a 1 per cent increase in the price of sheep meat causes a 0.23 per cent decrease in wool production. The negative relationship between the price of beef and wool supply indicates wool-beef substitution in the pastoral region. The negative coefficient of the price of sheep meat in the wheat supply equation also

Table 5 Short-run Morishima elasticity of substitution between input pairs in the pastoral region

Quantity	Input: Materials and services	Labour	Capital	Sheep numbers	Cattle numbers
Materials and services	0	−0.288	0.047	0.034	−0.021
		(−3.86)†	(0.55)	(0.43)	(−0.27)
Labour	0.470	0	0.545	0.377	0.628
	(3.79)		(3.71)	(3.67)	(4.41)
Capital	0.011	0.283	0	0.083	0.192
	(0.31)	(2.25)		(1.98)	(3.30)
Sheep numbers	0.051	0.044	0.176	0	0.064
	(1.39)	(0.89)	(4.32)		(2.94)
Cattle numbers	−0.010	0.563	0.097	0.109	0
	(−0.30)	(5.04)	(0.28)	(1.94)	

†Values in parentheses are *t*-ratios.

indicates wheat-sheep meat substitution, while the positive coefficient of the price of beef in the wheat supply equation indicates wheat and beef are complementary products in the pastoral region in both the short and long run.

The estimated own-price elasticities of output supplies and input demands for the pastoral region can be compared with those of previous Australian studies. Overall, the positive signs for elasticities reported in this study appear to conform to earlier Australian studies, although the estimates obtained here are somewhat lower. It is important to note that the estimated short-run own-price elasticity of wool supply reported in this study is less than 0.57 reported by Kokic *et al.* (1993) but higher than that reported by Vincent *et al*. (1980) and Fisher and Wall (1990), whose estimates were 0.08 and 0.1, respectively, for the pastoral region. The short-run own-price wheat supply elasticity reported in this study is substantially less than those reported in previous Australian studies (of between 0.31 and 2.67). The estimated short-run own-price elasticity of demand for labour reported in this study is similar to −0.5 as reported by Ryan and Duncan (1974), but less than −0.7 as found by McKay *et al*. (1983).

3.3 Morishima elasticity of substitution among inputs

The elasticity of substitution and the cross-price elasticity of demand for input pairs are both positive for substitutes and negative for complements. However, the elasticity of substitution estimates are more useful than cross-price elasticities in that they reflect the relative importance of inputs used in the production process (Binswanger 1974). Since the early 1930s, the importance of substitutability between inputs has featured prominently in the economic literature. This has led to several definitions, the two most common being the Allen-Uzawa elasticity of substitution, hereafter referred to as AES, proposed by Allen and Hicks (1934) and later by Uzawa (1962), and the Morishima elasticity of substitution, hereafter referred to as MES, proposed by Morishima (1967) and espoused by Blackorby and Russell (1975, 1989). Although the AES has been used extensively in the published econometric literature, Blackorby and Russell (1975) criticise it as being qualitatively and quantitatively uninformative. Sharma (2002) cites Blackorby and Russell (1989) to argue that 'the Morishima elasticity of substitution (MES) (i) is a measure of curvature or ease of substitution (ii) is a sufficient statistic for assessing – quantitatively as well as qualitatively – the effects of changes in price or quantity ratios on relative factor shares, and (iii) is a logarithmic derivative of a quantity ratio with respect to a marginal rate of substitution or a price ratio' (p. 883). Furthermore, as argued by Sharma (2002), the 'MES are better than the Allen-Uzawa elasticities for representing the factor substitution relationships because these explicitly explain the adjustment of factor combinations in response to relative price changes' (p. 131). The MES is often estimated for a cost function. However, Ball and Chambers (1982) and Chambers (1988), and more recently Sharma (2002), have provided a detailed exposition of the derivation of MES in the context of a profit function. This study adopts the approach proposed by Ball and Chambers (1982) in the derivation of MES for a profit function.

Tables 5 and 6 report estimates of the short-run and long-run estimates of MES_{ij} ($i, j =$ M, L, K, S, C; where M, L, K, S, and C denote materials and services, labour, capital, sheep numbers and cattle numbers, respectively) along with their *t*-ratios. Following Sharma (2002), the MES_{ML} represents the percentage change in materials and services to labour quantity ratio (M/L) when the relative price P_L/P_M is changed by changing P_L and holding P_M constant. The elasticity of substitution estimates of MES_{SK}, MES_{CL} and MES_{SC} are all positive and significantly different from zero in both the short and long run. The results indicate that sheep and capital, cattle and labour, and sheep and cattle are Morishima substitutes, irrespective of whether the price of one input rises relative to the other. The result reported in Table 5 also indicate that MES_{LC} is positive, suggesting that labour and capital are Morishima substitutes in the short run, irrespective of whether the wage rate rises or the price of capital rises. In addition, MES_{ML} is positive and statistically significant at a 5 per cent level,

Table 6 Long-run Morishima elasticity of substitution between input pairs in the pastoral region

	Input				
Quantity	Materials and services	Labour	Capital	Sheep numbers	Cattle numbers
Materials and services	0	0.211	0.128	0.100	0.026
		(3.54)[†]	(3.91)	(1.76)	(0.56)
Labour	0.153	0	0.494	0.410	0.689
	(3.71)		(2.43)	(3.59)	(4.32)
Capital	0.164	0.451	0	0.371	0.321
	(1.40)	(1.54)		(2.27)	(2.90)
Sheep numbers	0.035	0.024	0.128	0	0.102
	(0.81)	(0.40)	(1.72)		(1.93)
Cattle numbers	−0.004	0.610	0.080	0.106	0
	(−0.13)	(5.17)	(1.42)	(1.91)	

[†]Values in parentheses are *t*-ratios.

suggesting that materials and services and labour are Morishima substitutes in the short run.

A number of studies have estimated the elasticity of substitution between input pairs in Australian rural industries. Of particular relevance is the study by McKay *et al*. (1980), which provides estimates of AES between input pairs. There are, however, important differences between the McKay *et al*. (1980) study and the current study. First, in addition to covering a different time period, the McKay *et al*. (1980) study was an aggregate analysis for the Australian sheep industry while this study is for aggregate production in the pastoral region. Second, they employed a translog cost function while this study assumes a GL functional form. Third, the AES reported by McKay *et al*. (1980) is symmetric, while the MES reported in this study is asymmetric. Their estimates of substitution among inputs were higher than those reported in this study, possibly as a result of the failure of the McKay *et al*. (1980) study to account adequately for adjustment lags of quasi-fixed inputs. By implicitly assuming instantaneous adjustment, they considered farmers would respond quickly to changes in external stimuli.

In summary, the Morishima elasticity estimates are all less than one and generally positive indicating that a 1 per cent increase in the price of an input i relative to input j causes the demand for input j relative to the demand for input i to increase by less than 1 per cent. The implication is that the price-induced substitutability between pairs of inputs used in the pastoral region is low. Another interesting feature of the results is that in both the short run and long run, sheep and cattle production are Morishima substitutes, and Morishima substitution occurs between sheep and capital, and between cattle and labour. Although labour and capital are Morishima substitutes in the short run, they do not appear to be substitutes in the long run. The results suggest that while an increase in wages may induce a greater consumption of capital in the short run, a wage rise may cause a reduction in the use of capital in the long run. The short-run substitution between labour and capital may simply be a result of the labour shedding strategy of farmers in response to the dramatic decline in the price of wool in the early 1990s. While decreasing the number of people they employed, farmers may have increased their investment in capital stock.

4. Concluding remarks

The present study applies a dynamic optimal intertemporal investment model to Australia's pastoral sector. Results suggest that quasi-fixity is characteristic of agricultural production in Australia's pastoral region. Labour, capital, sheep numbers and cattle numbers are slow to adjust towards long-run optimal levels in response to changes in external stimuli. The rate of adjustment of labour and sheep numbers and of sheep numbers, and cattle numbers appear to be interdependent. That is, pastoralists make decisions about investment in the sheep and cattle industries jointly. As well, decisions about labour use and sheep numbers appear to be made jointly. This suggests that policies that influence the decision to invest in one of these inputs are likely to influence investment in the other. The findings that farmers make decisions about investment in sheep and cattle and between sheep and labour jointly in the pastoral region appear to conform to previous Australian studies. The results in the present study indicate that, in accounting for adjustment cost, output supply and input demand responses to changes in own-price are inelastic in both the short and long run. The implication is that changes in output and input prices would have little impact on production decisions in the short run, but the impact increases slightly over time.

Based on the model estimated, the results indicate that it takes less than four years for all inputs used in the pastoral region to adjust to their long run optimal levels. The shortest lag is for labour adjustment and the greatest lag is in capital adjustment. Perhaps, the relatively rapid adjustment of inputs reflects the success of the Commonwealth Government's assistance provided to farmers to overcome adjustment problems during the turbulent period 1979–1993. However, this is an issue for future research. The assumption that farmers form expectations about price statically may be excessively restrictive. Future investigations could attempt to relax this assumption to investigate the impact of a non-static expectation of farmers on investment behaviour in the pastoral region. Despite these limitations, the empirical results are useful and provide insights into the structure of production and investment in Australia's pastoral region during a period of economic challenge.

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