The Structure of Production and Investment in Australia's Pastoral Zone

By

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Abstract

This paper develops a dynamic optimal intertemporal investment model under the adjustment cost hypothesis to analyse the structure of production and investment in Australia's pastoral zone. The dynamic model is applied to pooled cross-sectional and time-series data obtained from ABARE farm surveys for the period 1979 through to 1993. Empirical results provide strong statistical evidence to indicate that quasi-fixity of inputs of labour, capital, sheep numbers and cattle numbers are characteristic of the agricultural sector in the pastoral zone. The results reveal that it takes about two years for labour, a little over three years of capital, a little over two years for sheep flock inventory and cattle herd inventory to adjust toward their long-run optimal levels. Results indicate substitution between labour-capital and sheep-cattle input pairs. The results also indicate that output supply and input demand responses are price inelastic in both the short and long run.

Key words: optimal intertemporal investment theory, quasi-fixity of inputs, adjustment costs, adjustment cost hypothesis, Australia's pastoral zone.

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1. Introduction

This paper examines the structure of production and investment in Australia's pastoral zone. Asset fixity is an issue of long-standing interest in agricultural economics. In Australia, it is well established that farmers are experiencing adjustment problems. The adjustment problem is often attributed to asset fixity in agriculture. The theory of asset fixity is defined in terms of the divergence between acquisition price and salvage value of durable assets. In 1950, Johnson (1950) extended the neo-classical theory of the firm to argue that an asset is fixed when its marginal value product in its present on-farm use neither justifies the acquisition of more of it nor its disposition. The theory of asset fixity recognises the importance of opportunity costs in the allocation of resources among alternative uses as well as clarifying the role of opportunity cost in the neo-classical theory of the firm (Hsu and Chang, 1990). In spite of the importance of adjustment costs of inputs in influencing production decision-making processes in agriculture, this aspect of production system has been ignored due to its complexity. The focus of this study is to model output supply and factor demand responses in an attempt to test for quasi-fixity of inputs used in the agricultural sector in Australia's pastoral zone.

Most previous studies of agricultural production have assumed static profit maximisation or cost minimisation models. A survey of these studies is presented in the study by Lopez (1982). These studies, hereafter referred to as the static optimisation approach, have essentially assumed explicitly or implicitly that all inputs adjust instantaneously toward their long run equilibrium (optimal) levels. Extensions of the static optimisation approach to account for dynamics in production behaviour involves essentially the use of variants of Nerlove's partial adjustment model.

There has been an extensive discussion of adjustment problem in Australian literature (Campbell, 1974; Musgrave, 1990; Gow and Stayner, 1995). Some previous Australian studies have attempted to account for adjustment lags in agriculture by incorporating levels of fixed inputs into output supply and factor demand response functions. These studies include those by Vincent et al. (1980), McKay et al. (1980, 1982; 1983) and Fisher and Wall (1990). Kokic et al. (1993) used the M-quantile regression technique to derive product supply equations. In their study, Kokic et al. (1993) specified a revenue maximisation problem for an individual firm whose objective is to maximise farm cash income subject to production technology and land area constraints. The imposition of constraints on the optimisation problem highlights the dynamic nature of agricultural production processes.

Although previous Australian studies have provided reliable estimates of output supply and factor demand responses in Australian agriculture, they are subject to the main criticism of the static optimisation models; its *ad hoc* empirical definition of asset fixity. Kulatilaka (1985) and Wall and Fisher (1988) criticise the static optimisation approach because it fails to explicitly account for the direction of the adjustment path and the length of time of adjustment of quasi-fixed inputs. Adams (1988) criticised previous Australian studies on the ground that the approaches used to specify the lag structure are arbitrary. Treadway (1970) argues that the use of variants of Nerlove's partial adjustment model to account for dynamics in production behaviour is *ad hoc* and not based on sound economic theory of the firm. Given that there is generally imperfect information available to farmers, it is likely that farmers may not make the full adjustment toward long-run equilibrium (optimal) levels within one year. This suggests that conscious effort must be made to develop a model that adequately accounts for adjustment lags in agricultural production in Australia.

A potentially important- but not fully researched area in Australian literature- is testing for quasi-fixity of inputs and estimating the rates of adjustment of quasi-fixed inputs used in the agricultural sector. To address these criticisms, this study differs from previous Australian analyses of production behaviour in three main respects. First, given the effect of quasi-fixed inputs in agricultural production decision-making processes, it is important that output supply and input demand response models be dynamic. Production behaviour is therefore modelled as a dynamic process based on optimal intertemporal investment theory of the firm and the adjustment cost hypothesis rather than the static optimisation approach used in previous Australian studies. Second, the optimal intertemporal investment modelling approach used in this study provides a means for testing for quasi-fixity of inputs of labour, capital, sheep numbers and cattle numbers, and also for estimating rates of adjustment of these inputs used in Australia's pastoral zone. Third, compared with most previous Australian studies, there is greater emphasis on accounting for the effects of adjustment costs of inputs on production decision-making in Australia's pastoral zone based on economic theory of the firm.

The seminal works of Lucas (1967), Treadway (1970) and Mortensen (1973), among others, have radically reshaped the modelling of production behaviour of economic agents. This approach, referred to in econometric literature as the optimal intertemporal investment modelling approach, was formalised by McLaren and Cooper (1980) and espoused by Epstein (1981a, b). Following closely the work by Howard and

Shumway (1988), this study aims to propose an alternative method for estimating the relationships among outputs supplied and inputs demanded by farmers. The empirical application is a dynamic multi-product econometric model of agricultural production in Australia's pastoral zone. The specific objectives of this study are:

1. to test for quasi-fixity of inputs of labour, capital, sheep numbers and cattle numbers;
2. to estimate the rates of adjustment of quasi-fixed inputs of labour, capital, sheep numbers and cattle numbers;
3. to estimate short-run and long-run own-price and cross-price elasticities of output supply and factor demands; and
4. to investigate the substitutability among inputs used in Australia's pastoral zone.

The rest of this paper is organised as follows. Section 2 presents the methodological framework used in this study. Section 3 discusses the sources and description of data. Section 4 presents the empirical results of the application of pooled cross-sectional and time-series data to the optimal intertemporal investment model developed in Section 2. Section 5 presents some concluding remarks of the paper.

2. The Model

Theoretical Framework

Consider the maximisation of the future stream of profits over an infinite horizon for a price-taking firm at a given point in time t=0, subject to technological constraints. Assume 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 adjustment costs. Assume further that the services flows of quasi-fixed inputs are proportional to their stock (Treadway, 1970). Let K and I denote the vector of quasi-fixed inputs and the vector of gross rate of physical investment of quasi-fixed inputs, respectively. Following Howard and Shumway (1988), the discounted future stream of profits is represented by an infinite horizon problem as

$$J(P, W, C, r, K) = \text{Max} \int_0^{\infty} e^{-rt} [P.F(X, K, \dot{K}) - W'X - C'K] \partial t \tag{1}$$

subject to $\dot{K} = I - \delta K$, $K(0) = K_0$, $X, K > 0$.

where J(.) is the profit function of the firm; P is price vector of outputs produced; W is price vector of variable inputs; C is price vector of quasi-fixed inputs; K is vector of stocks of quasi-fixed inputs; I is vector of physical investment in quasi-fixed inputs; r is real rate of discount; δ is a diagonal matrix whose k-th component denotes the depreciation rate of the k-th stock of quasi-fixed input; K_0 is initial endowment of K; $\dot{K}$ is vector of the optimal rate of net investment in quasi-fixed inputs; and the production function F(.) is finite, nonnegative, real-valued, continuous, smooth, monotonitic, convex in output and variable inputs, twice continuously differentiable, and bounded function (Lau, 1978, p. 171).

Assume that the profit function J(.) satisfies the regularity conditions of a profit function; that is, the profit function is a real-profit, non-negative, twice continuously differentiable, non-decreasing in P, non-increasing in W and C, decreasing in K and concave in W and C (Epstein and Denny, 1983; Fernandez-Cornejo et al., 1992). Assume further a constant real rate of discount. If the production function in Eq. (1) satisfies the above regularity conditions, then, the maximised profit function of the firm satisfies the Hamilton-Jacobi-Bellman equation for an optimal control problem (McLaren and Copper, 1980). Following Kamien and Schwartz (1981, p. 204), the Hamilton-Jacobi-Bellman equation can be expressed as

$$H[P, W, C, r, K] = F(X, K, \dot{K}) - W'X - C'K - V_x[I - \delta K_{t-1} + K(0)] \quad (2)$$

where K_{t-1} is one-year lag of vector of stock of quasi-fixed inputs; and the other variables are as defined above.

Given that the function F(.) in Eq.(2) satisfies all the regularity conditions of a production function, as defined above, it can be established (Dreyfus, 1966; Arrow and Kurtz, 1970) that the profit function J(.) in Eq. (1) is static. The dynamic profit function can then be expressed as

$$rJ(P, W, C, r, K) = \text{Max}\ [P\ F(X, K, \dot{K}) - W'X - C'K + J_k\ K]\ \partial t \quad (3)$$

where rJ(.) is the dynamic profit function; J_k is vector of shadow price of quasi-fixed inputs; and the other variables are as defined above.

The dynamic profit function rJ(.) in Eq. (3) is dual to $F(X,K,\dot{K})$ in Eq. (1) (Epstein 1981a). Conditional on the hypothesised optimising behaviour, the properties of $F(X,K,\dot{K})$ in Eq. (1) are manifest in the properties of $J(X,K,\dot{K})$ in Eq. (3) (Epstein, 1981a, b). Thus, a full dynamic duality exists between $rJ(X,K,\dot{K})$ and $F(X,K,\dot{K})$ (Taylor and Monson, 1985).

The inclusion of a variable to capture technical change in the derived output supply and factor demand equations is important for two main reasons. First, it provides explicit technical interactions between activities within the agricultural sector. Second, it helps to maintain consistency with the theoretical requirements of a profit function (Martin and Alston, 1994).

A number of studies have incorporated a time trend variable to capture the effects of technological change on output supply and factor demands. This includes studies by McKay et al. (1980), Lopez (1985), Howard and Shumway (1988) and Fisher and Wall (1990). This approach has one limitation, viz. it imposes curvature restrictions on the estimated model (Howard and Shumway, 1988). Despite this limitation, the use of a time trend variable to capture technical change reflects the effect of technical change on agricultural production (Vasavada and Chambers, 1989). As Baltagi and Griffin (1988) note, the use of the standard time trend variable to capture disembodied technical change remains the norm. Incorporating research and development expenditure as a measure of technical change may improve the estimated parameters of the model. This measure, however, would capture only embodied technical change. The focus of this study is to examine the effect of disembodied technical change- technology within the control of the farmer- on output supply and factor demands. This study follows previous Australian studies by including in the dynamic model a time trend variable to capture the effects disembodied technical change , and expressed as H(t), where t is a time trend variable. Incorporating technical change into Eq. (3) yields

$$rJ(P, W, C, r, K, t) - J_h \dot{H} = \text{Max}[P.F(X, K, \dot{K}) - W'X - C'K + J_k \dot{K} - J_h \dot{H}]\partial t \qquad (4)$$

where $\dot{H}$ is the net change in H, and the other variables are as defined above.

Given the dynamic profit function in Eq. (4), the necessary condition for the application of the Envelope Theorem is achieved when the first derivatives of the profit function rJ(.) in Eq. (4) equals zero. Invoking the first-order conditions of the Envelope Theorem, the first differential of rJ(.) in Eq. (4) with respect to output and input prices yield conditional set of output supply, variable input and quasi-fixed input demand equations, following Howard and Shumway (1988), as follows:

Supply equation

$$F_p(P, W, C, K, t) = rJ_p - J_{kp}\dot{K} - J_{hp}\dot{H} \qquad (5a)$$

Variable input demand equation

$$X_w(P, W, C, K, t) = rJ_w + J_{kw}\dot{K} - J_{hw}\dot{H} \qquad (5b)$$

Quasi-fixed input demand equation

$$\dot{K}_c(P, W, C, K, t) = J_{kc}^{-1}(rJ_c + K - J_{hc}\dot{H}) \tag{5c}$$

A review of previous studies that used the optimal intertemporal investment modelling approach revealed that two main approaches used to specify the dynamic profit function rJ(.) in Eq. (4) are: the modified generalised Leontief functional form (Howard and Shumway, 1988; Krasachat and Coelli, 1995), and the normalised quadratic functional form (Chambers and Vasavada, 1983; Epstein and Denny, 1983; Taylor and Monson, 1985; Lopez, 1985; Vasavada and Ball, 1988). This study assumes production technology to be characterised by modified generalised Leontief (GL) functional form. The GL functional form is chosen for the following reasons. First, it satisfies the regularity conditions for a profit function. Second, it provides a robust result for testing theoretical properties underlying the functional form; it maintains the flexible accelerator investment properties that are essential properties in the derivation of the quasi-fixed input demand functions. Third, it imposes fewer restrictions on the estimated equations, and fourth, it satisfies the Hamilton-Jacobi-Bellman Equation of the profit function with properties of linear homogeneity in prices and concavity in quasi-fixed inputs.

Despite the flexibility and ease of implementation of the generalised Leontief model, it often fails the regularity conditions (Lawrence, 1988). It is suggested in the literature to impose restrictions on the estimated model in order that the model satisfies the regularity conditions. However, there is a problem associated with the generalised Leontief model, viz. it is extremely difficult to restrict and maintain regularity properties (Howard and Shumway, 1988). Attempts to restrict and maintain regularity properties will make the already complex model intractable. Hence, no attempt is made to maintain regularity properties of the profit function in this study.

Empirical model of the agricultural sector in the pastoral zone

The profit function representing output supply and factor demand responses subject to quasi-fixity of inputs is approximated, following Howard and Shumway (1988), by a generalised Leontief function:

$$\begin{aligned} rJ(P, W, C, K, t) = {} & [PW']AK + C'B^{-1}K + [P^{0.5}W^{0.5}]EC^{0.5} + [C^{0.5}FC^{0.5}] \\ & + [P^{0.5}W^{0.5'}]G[P^{0.5}W^{0.5'}]' + TH[PW'C]' \end{aligned} \tag{6}$$

where P is a (2x1) vector of output prices of wool and wheat; W is a (1x1) scalar of price of variable input (materials and services); C is a (4x1) vector of prices of quasi-fixed inputs (C_1 is price of labour, C_2 is price of capital; C_3 is price of sheep meat; C_4 is price of beef); K is a (4x1) vector of quasi-fixed inputs (K_1 is labour; K_2 is capital; K_3 is sheep numbers; K_4 is cattle numbers); T is a time variable to capture disembodied technical change; and A, B-1, E, G and F are parameters, each a (7x7) matrix, and H is a (1x7) matrix.

3. Data

The required data for the analysis consist of prices and quantity indices of outputs of wool and wheat and inputs of materials and services, labour, capital, sheep and cattle. Pooled cross-sectional and time-series quantity data for outputs for the pastoral zone, for the period 1979-1993, were obtained from Australian Bureau of Agricultural and Resource Economics (ABARE) farm surveys. The data used in the analysis consist of six regions based on ABARE's regional classification. Indices of prices paid for inputs and prices received by farmers for outputs were obtained from *Commodity Statistical Bulletin* 1994 (and earlier editions) (ABARE, 1994). Wool output was measured as total wool produced in kilo tonne greasy. Wheat output was measured as total wheat produced in kilo tonnes.

The data on materials and services include expenditures on repairs to plant, repairs to structures, livestock materials, pesticide and sprays, insurance, fodder, fertiliser, seed, packaging materials, electricity, fuel, oil, grease, insurance, rates and taxes, accounting charges and advisory services. Implicit quantity indices for materials and services were obtained by dividing the expenditure by an index of prices paid by farmers for materials and services. Labour was treated as a fixed input and measured by the index of the total number of weeks worked in a given year in the agricultural sector, and includes the number of weeks worked by hired labour, family labour and operator labour. It is important to note that the total labour force available for agricultural production depends on the quality of labour which in turn is influenced by managerial abilities, technical skills and education levels (Powell, 1974). No adjustment has been made to account for quality differences in this study. However, the adjustment for quality of labour is captured by productivity gain and is reflected in the disembodied technical change variable included in the model.

Capital is another fixed variable. The service flow from capital is assumed to be proportional to capital stocks, which consist of opportunity cost, depreciation, maintenance and capital gain. Maintenance expenditure is not included in the calculation, but are included in the materials and services category. Following Fisher and Wall (1990), capital gains are treated as unrealised output in this study and hence were not included in the calculations. Hence, implicit quantity indices for capital were obtained by dividing the expenditure by an index of prices paid by farmers for capital. The other fixed variables are sheep and cattle inputs. Following Fisher and Wall (1990), the quantity of service flow of sheep and cattle inputs was measured as opening numbers on the property.

4. Empirical Results

The dynamic model for the pastoral zone was estimated using pooled cross-sectional and time-series data for the period 1979-1993. The output supply of wool and wheat equations, variable input demand for materials and services, and quasi-fixed input demand equations for labour, capital, sheep and cattle were appended with an error term to reflect errors of optimising behaviour as a result of the unexplained changes in dependent variables. The error terms of each output supply and input demand response equation were assumed to be additive and satisfy the classical assumptions of Ordinary Least Squares. That is, the error term is normally distributed with a zero population mean, constant variance and uncorrelated across equations and within equations. Given that most agricultural markets are unstable due to fluctuations in supply and demand, current prices are likely to approximate the efficient market hypothesis (Fama, 1970). In this study, therefore, producers are assumed to form expectations statically. The maintained structural model is recursive in nature, and hence the system of equations was estimated by the iterative non-linear seemingly unrelated least squares (ISURE) procedure in SHAZAM (Version 7.0) econometric package. The estimation algorithm used to obtain the parameter estimates of the dynamic model is the Davidson-Fletcher-Powell algorithm. The estimation converged after 140 iterations. The ISURE parameter estimates obtained are asymptotically equivalent to the Maximum Likelihood estimates at the point of convergence (Vasavada and Ball, 1988).

Table 1 reports parameter estimates and asymptotic t-statistics of the dynamic model for the pastoral zone. Nearly all the estimated parameters are asymptotically significant at a 10% level. Dummy variables were included in the model to capture variations in production technology across regions. Parameter estimates of the dummy variables are not reported in this paper.

Table 1

Seemingly unrelated estimate s of the dynamic model
for the pastoral zone in Australia

Parameter	Estimate	t-ratio	Parameter	Estimate	t-ratio
A11	-2.199	-11.260	H4	-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	F12	-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
G14	6.866	5.604	F23	0.390	0.404
H1	-0.367	-2.272	F24	-2.233	-1.185
A21	-1.563	-1.736	F33	-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	H5	0.217	0.736
E21	-7.299	-3.498	H6	1.555	4.259
E22	1.966	1.739	H7	0.365	1.988
E23	-19.283	-6.535	H8	-0.644	-3.157
E24	20.658	8.907	B22	-0.342	-7.932
G22	5.566	3.924	B21	-0.092	-1.161
G24	-10.396	-5.890	B23	0.580	4.433
H2	2.376	3.351	B24	-0.411	-5.606
A41	2.619	6.875	B33	-0.536	-10.139
A42	-4.313	-21.104	B31	-0.085	-2.633
A43	-4.875	-6.450	B32	0.075	4.224
A44	5.804	11.062	B34	-0.169	-3.391
E41	-3.759	-2.269	B44	-0.513	-7.754
E42	0.534	0.503	B41	0.257	4.616
E43	4.659	1.739	B42	-0.164	-5.209
E44	15.380	8.615	B43	0.013	0.166
G44	-13.441	-4.252			

A generalised measure of goodness-of-fit of the dynamic model is computed, following Baxter and Cragg (1970) as, R^2-adj. $=1-\exp[2(L_0-L_1)/N]$, where L_0 is the sample maximum of the log-likelihood ratio when all slope coefficients are zero, L_1 is the sample maximum of log-likelihood when some or all of the slope coefficients are unconstrained, and N is the total number of observations. The estimated value of the generalised measure of goodness-of-fit is close to 1. It follows that the dynamic model has a high degree of explanatory power. The estimated Durbin-Watson (D-W) test statistic range from 1.79 for the estimated sheep equation to 2.45 for the labour equation. No evidence of serious autocorrelation problem is indicated.

The hypotheses of linear homogeneity and concavity in quasi-fixed inputs have not been tested because the assumptions are maintained by the generalised Leontief functional form (Howard and Shumway, 1988). Test for symmetry was not performed because symmetry in parameters were imposed on the estimated model by constraining the appropriate cross-partial derivatives to be equal (Coxhead, 1992). Test for convexity in prices of the profit function is performed by testing the null hypothesis that the profit function satisfies convexity condition against the alternative hypothesis that the profit function does not satisfy the convexity condition. Following Howard and Shumway (1988), convexity in prices is satisfied if the following condition hold: $e_{ij}<0$ for i,j =1,...,n, $f_{ij}<0$ and $g_{ij}<0$ for $i \neq j$ where e_{ij}, f_{ij} and g_{ij} are the parameter estimates of the dynamic model. Since the calculated Chi-square value of 262.2 is greater than critical value of 32.67 at a 5% level for 21 degrees of freedom, we reject the null hypothesis that the profit function satisfies the convexity condition. It is important to note that some authors in Australia, for example, McKay et al. (1980, 1982) and Fisher and Wall (1990), who used different functional forms have reported that their model fail the convexity condition. Other studies such as those by Taylor and Monson (1985) who used the normalised quadratic functional form and Krasachat and Coelli (1995) who used the generalised Leontief functional form, have reported that their model fail the convexity condition. The Australian studies are of particular interest because they used similar data set as the one employed in this study. This suggests that the failure of the profit function to satisfy convexity condition is not specific to this study.

Testing for biases of disembodied technical change on output supply and factor demands

The time trend variable included in the estimated model to capture the effect of disembodied technical change on output supply and factor demands is assumed to act as a shifter of the output supply and factor demand equations. The signs of the parameter estimates of the technical change variable give information about the nature of biased technical change in agricultural production in the pastoral zone. A positive (negative) coefficient of the disembodied technical change variable in equation of output supply implies that disembodied technical change led to an increased (decreased) production of the product. On the other hand, a positive (negative) coefficient of the disembodied technical change variable in equation of input demand equations indicates input-using (input-saving) disembodied technical change.

Based on the signs of the parameters of the technical change variable in output supply and factor demand equations, disembodied technical change tended to reduce wool production while increasing wheat production in the pastoral zone during the period 1979 to 1993. It is surprising that the coefficient of the technical change variable in equation of wool supply is negative. Two possible reasons exist for this paradoxical result. First, the negative coefficient of the technical change variable in equation of wool supply may be due to the inability to adequately account for the structural characteristics in the wool industry. Second, it is possible that the technical change variable is capturing the dramatic decline in wool production a consequence of the dramatic decline in the price of wool since the late 1980s. Capital exhibited factor using technical change. Sheep and cattle stock also exhibited factor using technical change, resulting in a decrease in sheep flock and cattle herd inventories. The null hypotheses of neutral technical change in materials and services and labour equations could not be rejected at a 5% level of significance and 2 degrees of freedom.

Structural tests for quasi-fixity of inputs in the pastoral zone

Structural tests for quasi-fixity of inputs involve two tests, namely, a test for *independent adjustment* of inputs and a test for *instantaneous adjustment* of inputs. Following Vasavada and Ball (1988), the derived equations of quasi-fixed inputs (Equation (5c)) above can be re-written in the form:

$$\dot{K} = M[K - \overline{K}] \tag{7}$$

where M is a matrix which is given by $B + J_{kc}^{-1}$; and $\overline{K}$ denotes a vector of quasi-fixed inputs.

In order to carry out structural tests, likelihood ratio tests were performed. If Λ denotes the maximised log-likelihood, the log-likelihood ratio (LLR) statistic is given by LLR = 2 (Λ_0 - Λ_A), where Λ_0 is the log-likelihood under the null hypothesis and Λ_A is the log-likelihood when the null hypothesis is relaxed. Theil (1971) demonstrated that the LLR is asymptotically distributed as a Chi-square distribution under the null hypothesis (H_0), with degrees of freedom equal to the number of restrictions that define H_0 with respect to the alternative hypothesis (H_A).

Test for instantaneous adjustment of inputs involves testing whether the inputs adjust instantaneously in one year towards their long run equilibrium levels. The null hypothesis is that inputs of labour, capital, sheep and cattle adjust instantaneously against the alternative hypothesis that these inputs do not adjust instantaneously in one year towards their long-run equilibrium levels. Mathematically, this can be expressed, following Howard and Shumway (1988), as

$$H_0: \; M_{ii} = -1 \text{ and } M_{ij} = 0 \;\text{ against }\; H_1: \; M_{ii} = -1 \text{ and } M_{ij} \neq 0 \tag{8}$$

where M is the adjustment matrix, i and j denote quasi-fixed inputs (where i, j = 1,..., 4, for labour, capital, sheep and cattle, and where $i \neq j$).

Test for independent adjustment of inputs involves testing whether the rate of adjustment of quasi-fixed inputs is independent of the degree of equilibrium in the level of adjustment of the other quasi-fixed input (Taylor and Monson, 1985). The null hypothesis is that pairs of inputs do not adjust independently of each other, against the alternative hypothesis that these inputs adjust independently of each other. Mathematically, this can be expressed, following Howard and Shumway (1988), as

$$H_0: \quad M_{ij} = M_{ji} = 0 \qquad \text{against} \qquad H_1: \; M_{ij} = M_{ji} \neq 0 \tag{9}$$

where M is the adjustment matrix, i and j denote quasi-fixed inputs (where i, j = 1,..., 4, for labour, capital, sheep and cattle, and where $i \neq j$).

Results of the hypothesis testing procedure for the structure of production in the pastoral zone are reported in Table 2. The results indicate that, for tests for independent adjustment of inputs, at the 5% significant level, the calculated likelihood ratio statistic is found to exceed the critical value of 9.49 for 4 degrees of freedom in all cases. The results also indicate that the calculated likelihood ratio statistics for tests for independent adjustment of inputs exceed the critical value of 5.99 at a 5% level of significance and 2 degrees of freedom. The exception is labour-sheep and cattle-sheep pairs of inputs for which the null hypothesis that inputs do not adjust independently could not be rejected at a 5% level of significance and 2 degrees of freedom.

In summary, the structural tests for quasi-fixity of inputs yield important findings. The empirical tests of the hypotheses of perfectly variable factor demands for labour, capital, sheep and cattle are tested and conclusively rejected in the pastoral zone. This indicates that the assumption that all inputs adjust instantaneously as explicitly or implicitly in output supply and input demand response analyses for the pastoral zone is inappropriate. Clearly, the results indicate that the quasi-fixity of inputs is characteristic of agricultural production in the pastoral zone in Australia. This confirms the notion of adjustment problem in Australian agriculture (Campbell, 1974; Musgrave, 1990; Gow and Stayner, 1995), especially in the pastoral zone. The results also indicate that the hypothesis of independent adjustment of input pairs is conclusively rejected. Given that independent adjustment of labour-sheep and sheep-cattle input pairs could not be rejected, this suggests joint production decision-making on sheep and cattle enterprises in the pastoral zone in Australia.

Table 2

Chi-square statistics of tests of hypotheses of quasi-fixity of inputs in Australia's pastoral zone, 1979-93

Hypothesis	Pastoral Zone
Instantaneous adjustment[a]	
Labour	347.64
Capital	1,041.24
Sheep	397.43
Cattle	301.13
Independent adjustment[b]	
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

[a]The critical value at a 5% level of significance and 4 degrees of freedom is 9.49.
[b]The critical value at a 5% level of significance and 2 degrees of freedom is 5.99.

Estimated rates of adjustment of quasi-fixed inputs in the pastoral zone

The estimated parameters of the adjustment matrix M for the accepted model and those reported in previous studies are reported in Table 3. Adjustment coefficients provide information on the relative speed of adjustment of quasi-fixed inputs towards their long run optimal levels. No previous Australian studies have estimated the rates of adjustment of quasi-fixed inputs, hence there are no estimates for comparison. The numerical estimates of the adjustment matrix M for the pastoral zone yield the following conclusions. Labour took nearly two years to adjust to desired values. Capital predicted the longest adjustment lag of a little over three years. A possible reason for the sluggish adjustment of capital in the pastoral zone is that capital cannot be deployed into the production of other farm products due to its physical characteristics. Furthermore, in periods of declining prices of agricultural products- as experienced in Australian commodity market in recent past- farmers are unlikely to deploy resources in the production of other farm products. Sheep flock inventory adjusts at a rate of about two years, while it takes a little over two years for cattle herd inventory to adjust in the pastoral zone.

A comparison of the estimated rates of adjustment of inputs reported in Table 3 show that labour adjusts more rapidly in the pastoral zone than in the US agriculture. This result demonstrates that the rigid adjustment of labour in US agriculture, which Vasavada and Ball (1988) attributes to the specific human capital embodied in choice of farming as an occupation, appear to be less prevalent in Australia's pastoral zone. Interestingly, with the exception of Vasavada and Chambers (1986) and Krasachat and Coelli (1995), the estimated rate of adjustment of capital reported in this study is less than those reported in studies abroad. This suggests rigid adjustment in the capital market in the pastoral zone in Australia. Notably, no previous study have estimated the rates of adjustment of sheep numbers, hence there are no estimates for comparison. Estimated rate of adjustment of cattle of -0.45 reported in this study for the pastoral zone is higher than -0.04 reported by Howard and Shumway (1988) for cow numbers for US dairy industry.

Table 3

Comparison of the rates of adjustment of quasi-fixed inputs in the pastoral zone in Australia with studies abroad

Author and year	Input			
	Labour	Capital	Sheep	Cattle
This study				
Pastoral zone	-0.51	-0.28	-0.48	-0.45
Tyrchniewicz and Schuh (1969)	-0.25	-	-	-
Berndt et al. (1981)	-	-0.47	-	-
Lopez (1985)	-	-0.43	-	-
Taylor and Monson (1985)	-	-0.55	-	-
Vasavada and Chambers (1986)	-0.069	-0.118	-	-
Howard and Shumway (1988)	-0.40	-	-	-0.04[a]
Krasachat and Coelli (1995)	-0.34	-0.03	-	-

[a]Estimated for cow numbers.

The estimated own-price and cross-price elasticities of output supply and factor demands

The short and long run own-price and cross-price elasticities of output supply and factor demands are reported in Tables 4 and 5, respectively. The short-run elasticity estimates measure the effects of prices on output or inputs when the levels of quasi-fixed inputs used in agricultural production are fixed. In the long run, all inputs are variable. All the own-price elasticities of output supply and factor demands have the expected signs and inelastic in both the short and long run, with few exceptions.

The own-price elasticity estimates of output supply and input demands increased over time, conforming to the Le Chartelier principle. Short-run own-price supply elasticity range from 0.2 for wheat to 0.209 for wool, increasing over time to become 0.275 for wool and 0.285 for wheat in the long run. Short and long run own-price elasticities of demand for labour are -0.404 and -0.445, respectively. Capital appears to be least responsive to own-price, implying that policies aimed at influencing the cost of capital would not be very successful in influencing the demand for capital in the pastoral zone in Australia. The own-price elasticities of sheep and cattle are negative in both the short and long run. A possible reason for the negative short-run own-price elasticity of sheep and cattle numbers is the adjustment lags of these inputs toward their long-run optimal levels (Reynolds and Gardiner, 1980). However, the negative long-run own-price elasticity estimates are counter-intuitive and difficult to rationalise.

An interesting feature of the results reported in Tables 4 and 5 is that the price of sheep meat is statistically non-significant in influencing wool production in the short run. However, it becomes important in influencing wool production decision-making processes in the long run. Wool and sheep meat are competitive products in the long run. A one percent increase in the price of sheep meat causes a 0.232 percentage decrease in wool production in the long run. The negative relationship between the price of beef and wool supply indicates wool-beef substitution in the pastoral zone. This suggests that the transformation effect has dominated the expansion effect. The negative coefficient of the price of sheep meat in the wheat supply equation indicates wheat-sheep meat substitution in the pastoral zone. The positive coefficient of the price of beef in the wheat supply equation indicates wheat and beef are complementary products in the pastoral zone. This suggests that the expansion effect of a change in relative price has more than offset the associated transformation effect (Adams, 1988).

Table 4

Short-run elasticities of output supply and input demand: Generalised Leontief profit function for Australia's pastoral zone

Dependent Variable	Elasticity with respect to price of						
	Wool	Wheat	Materials[a]	Labour	Capital	Sheep	Beef
Wool supply	**0.209**	-0.172	0.279	0.093	-0.161	0.011	-0.241
	(4.03)[b]	(-2.34)	(6.75)	(2.54)	(-5.05)	(0.31)	(-6.12)
Wheat supply	-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[a]	-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 numbers	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 numbers	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)**

[a]Denotes materials and services.
[b]Values in parentheses are t-ratios.

Table 5

Long-run elasticities of output supply and input demand: Generalised Leontief profit function for Australia's pastoral zone

Dependent Variable	Elasticity with respect to price of						
	Wool	Wheat	Materials[a]	Labour	Capital	Sheep	Beef
Wool supply	**0.275**	-0.065	0.250	0.105	-0.120	-0.232	-0.198
	(4.83)[b]	(-0.80)	(5.60)	(3.50)	(-4.01)	(-6.67)	(-4.30)
Wheat supply	-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[a]	-0.129	0.144	**0.047**	0.082	-0.001	-0.029	-0.104
	(-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 numbers	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 numbers	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)**

[a]Denotes materials and services.
[b]Values in parentheses are t-ratios.

The relationship between wool and wheat is unclear. In the short run, the price of wool has no effect on wheat production. However, a rise in the price of wheat causes a fall in wool production. It is interesting to note that, in the long run, the price of wool is statistically non-significant in influencing wheat production, while the price of wheat is statistically non-significant in influencing wool production in the pastoral zone in the long run

Another interesting feature of the results reported in Tables 4 and 5 is that the cross-price elasticity of wool (wheat) supply with respect to the price of labour is positive (negative). The cross-price elasticity of wool supply with respect to the price of capital is negative (positive). The results indicate that while wool output is relative intensive in its use of capital, it is relatively less intensive in the use of labour. This probably reflects the dramatic decline in wool supply in recent years, a consequence of the dramatic decline in the price of wool. On the other hand, wheat output is relative intensive in the use of labour while relatively less capital intensive in the pastoral zone.

The negative short-run cross-price elasticity of wool supply with respect to the price of beef reported in this study is consistent with those reported by Vincent et al. (1980), Fisher and Wall (1990) and Kokic et al. (1993) for the pastoral zone. Interestingly, the cross-price elasticity of wool supply with respect to the price of beef reported in this study appear to be higher than those reported in most previous Australian studies. This suggests that farmers are becoming more responsive to changes in price of beef under recent changing economic conditions. It is important to note that, in the short run, the cross-price elasticity of wool supply with respect to the price of beef is greater than own-price elasticity estimate. A possible reason for this occurrence is the dramatic decline in the price of wool in recent past. However, it is interesting to note that, in the long run, the price of wool appears to be the most important factor driving wool production in the pastoral zone. This probably reflects woolgrowers' expectation of future increases in the price of wool.

Comparison of elasticities of output supply and input demands

Table 6 compares the own-price elasticities of output supply of wool and wheat reported in this study with those of previous Australian studies. The positive own-price elasticities of output supplies of wool and wheat reported in this study are consistent with those of previous Australian studies. However, the output supply elasticity estimates reported in this study are generally small relative to those reported by previous Australian studies. For example, Fisher and Munro (1983) estimated the own-price elasticity of wool supply for the pastoral zone to be 0.52 and McKay et al. (1983) reported 0.72 for the price of wool and sheep. Dewbre et al. (1985) reported a medium-term elasticity estimate of 0.4 for wool, while Hall et al. (1985) and Kokic et al. (1993) estimated the own-price elasticity of wool supply to be 0.6 and 0.57, respectively. The short-run own-price elasticity of wheat supply reported in this study is substantially less than those reported by previous Australian studies. Vincent et al (1980) estimated the own-price elasticity of wheat to be 1.0 for the pastoral zone, McKay et al. (1983) reported 0.5 for crops and Fisher and Wall (1990) reported 2.67 for the pastoral zone. Kokic et al. (1993) estimated the own-price elasticity of wool for the pastoral zone to be 0.31. The relatively high own-price elasticity of wool supply reported by McKay et al. (1983) is probably due to aggregation of wool and sheep outputs in their study. The estimated long-run own-price elasticity of wool supply reported in this study is small relative to both Dewbre et al.'s (1985) estimate of 1.0, and Hall et al's. (1988) estimate of 2.5.

Table 6

A Comparison of alternative own-price elasticities of output supply

Author and year	Wool supply		Wheat supply	
	Short run	Long run	Short run	Long run
This study				
Pastoral Zone	0.209	0.275	0.200	0.285
Vincent et al. (1980)	0.08	-	1.00	-
Fisher and Munro (1983)	0.52	-	-	-
McKay et al. (1983)	0.72[a]	-	0.50[b]	-
Dewbre et al. (1985)	0.40[c]	1.0		
Adams (1987)	0.46			
Hall et al. (1988)	0.6[c]	2.5		
Fisher and Wall (1990)	0.10	-	2.67	-
Kokic et al. (1993)	0.57	-	0.31	-

[a]Price of sheep and wool.
[b]Price of crops.
[c]Medium-term elasticity estimate.

The own-price elasticity of demand measures the the change in quantity demanded of an input in response to a change in its own price. The estimated short-run own-price elasticity of demand for labour reported in this study compare reasonably well to Ryan and Duncan's (1974) estimate of -0.5, but less than McKay et al.'s (1983) estimate of -0.7. Ignoring the significance of the elasticity estimate, the short-run own-price elasticity of demand for capital reported in this study is generally small in magnitude than those of previous Australian studies.

The Morishima elasticity of substitution of inputs in the pastoral zone

Tables 7 and 8 provide information on the estimated Morishima elasticity of substitution (MES) between input pairs in the pastoral zone. the MES is defined as the logarithmic derivative of a factor quantity ratio with respect to the corresponding factor price ratio. The MES therefore measure the percentage change in the ratio of two factors of production in response to a 1% change in the corresponding relative price ratio. The MES and the cross-price elasticities of demand for inputs are positive for substitutes and negative for complements. These relationships are easier to evaluate by examining the MES because the MES estimates reflect the relative importance (or share) of factors (Binswanger, 1974).

Table 7

Short-run Morishima Elasticity of Substitution between
Input pairs in the pastoral zone

Input j	Input I				
	Materials[a]	Labour	Capital	Sheep numbers	Cattle numbers
Materials[a]	0	-0.288 (-3.86)[b]	0.047 (0.55)	0.034 (0.43)	-0.021 (-0.27)
Labour	0.470 (3.79)	0	0.545 (3.71)	0.377 (3.67)	0.628 (4.41)
Capital	0.011 (0.31)	0.283 (2.25)	0	0.083 (1.98)	0.192 (3.30)
Sheep numbers	0.051 (1.39)	0.044 (0.89)	0.176 (4.32)	0	0.064 (2.94)
Cattle numbers	-0.010 (-0.30)	0.563 (5.04)	0.097 (0.28)	0.109 (1.94)	0

[a]Denotes materials and services.
[b]Values in parenthesis are t-ratios.

Table 8

Long-run Morishima elasticity of substitution between input pairs in the pastoral zone

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

[a]Denotes materials and services.
[b]Values in parenthesis are t-ratios.

An interesting feature of the MES estimates reported in Tables 7 and 8 is that the values appear to be significantly different from zero. However, the MES estimates are low. The magnitude of the MES estimates suggest that price-induced substitutability between inputs used in the pastoral zone has been very low. The implication is that pairs of inputs have not been good substitutes (Kudora, 1987).

The estimated MES estimates reported in this study are generally consistent with the Allen-Uzawa elasticity of substitution (AES) estimates between labour and capital reported by previous Australian studies. It is important to note that the short-run MES between labour and capital reported in this study is higher than Vincent's (1977) AES estimate of 0.1. Importantly, the results indicate that substitution exists between labour-capital, labour-cattle, sheep-capital and sheep-cattle input pairs in the short run. In the long-run, substitution appears to exist between labour-materials and services, labour-cattle, capital-sheep and sheep-cattle input pairs.

A number of studies have estimated the elasticity of substitution between input pairs in Australian agriculture. Of particular relevance is the study by McKay et al. (1980). McKay et al.'s (1980) study provides measures of Allen-Uzawa partial elasticity of substitution between inputs pairs. There are however important differences between McKay et al.'s (1980) study and the current study. First, in addition to different sample period, McKay et al. (1980) study was an aggregate Australian analysis for the sheep industry while this study is for aggregate production in the pastoral zone. Second, McKay et al. (1980) specified the production technology to be characterised by a translog cost function while this study assumes a generalised Leontief functional form. Third, it is also important to note that the Allen-Uzawa elasticity of substitution reported by McKay et al. (1980) is symmetric, while the MES reported in this study is asymmetric.

Broadly, the McKay et al. (1980) study finds high elasticity of substitution between pairs of inputs compared to the low values reported in this study. One possible reason for the difference in elasticity estimates is the failure on the part of McKay et al. (1980) to adequately account for adjustment lags of quasi-fixed inputs. By assuming instantaneous adjustment, McKay et al.'s (1980) study allows farmers to respond more quickly to changes in external stimuli, hence one would expect the estimated elasticity of substitution between inputs pairs to be high. Generally, substitution between materials and services-capital, cattle-capital and sheep-capital input pairs in the pastoral zone appear to be consistent with the substitution between livestock and capital observed by McKay et al. (1980).

5. Concluding Remarks

This study has applied optimal intertemporal investment theory in the context of adjustment cost hypothesis to analyse the structure of production and investment in Australia's pastoral zone. The dynamic model is applied to pooled cross-sectional and time-series data obtained from ABARE farm surveys for the period 1979 through to 1993. The optimal intertemporal investment framework has the advantage of enabling output supply and factor demand equations to be derived in the context of adjustment cost hypothesis. This is of great importance in econometric analysis, particularly in agriculture, where adjustment costs of inputs play an important role in influencing production decision-making processes.

The application of the model to data from the agricultural sector in the pastoral zone demonstrates the importance for accounting for adjustment costs of inputs in output supply and input demand response analyses. Empirical results provide strong statistical evidence to indicate that quasi-fixity of inputs of labour, capital, sheep numbers and cattle numbers are characteristic of agricultural production in the pastoral zone. Empirical results reveal that it takes about two years for labour, a little over three years of capital, little over two years for sheep flock inventory and cattle herd inventory to adjust toward their long-run optimal levels. The empirical results also indicate that disembodied technical change tended to reduce wool production while increasing wheat production in the pastoral zone. Disembodied technical change was biased towards using capital. Sheep and cattle stocks exhibited factor using technical change resulting in the disposal of sheep and cattle. Clearly, the results indicate that policies aimed at influencing the cost of capital, such as changes in interest rates, would not have appreciable effect in influencing the demand for capital in the pastoral zone. The empirical results indicate that, in the short run, substitution exists between labour-capital, labour-materials and services and sheep-cattle input pairs. In the long run, substitution appear to exist between labour-capital, labour-materials and services, labour-cattle, capital-sheep and sheep-cattle input pairs. Output supply and input demand relationships are all price inelastic in both the short and long run in Australia's pastoral zone. The empirical results are not fully consistent with the underlying assumptions of the estimated model. Although the elasticity estimates reported in this study provide helpful information about producer behaviour and technology in the agricultural sector in the pastoral zone, inferences must be interpreted with caution.

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