Optimal intertemporal investment in Australian agriculture: An empirical investigation

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Abstract

sectional and time-series farm survey data spanning the period 1979-1993. The model captures intertemporal investment behaviour of farmers, including independent and instantaneous adjustment decisions. Empirical test results indicate that labour, capital, sheep numbers and cattle numbers adjust sluggishly towards their long-run equilibrium levels. Results provide empirical evidence to indicate that adjustment problem is characteristic of production in agricultural zones Australia.

Key words: *Australia, agricultural zones, optimal intertemporal investment model, quaxi-fixity, adjustment costs*

JEL: C12, C13, C33, C61

Introduction

Rural production is typically influenced by factors such as variations in relative price of outputs and inputs. The adjustment problem faced by farmers is often attributed to asset fixity in agriculture, which is defined in terms of the divergence between acquisition price and salvage value of durable assets. This theory recognises the importance of opportunity costs in the allocation of resources among alternative uses and clarifies the role of opportunity cost in the neoclassical theory of the firm (Hsu and Chang, 1990). The underlying premise of the adjustment cost hypothesis is that farmers incur costs in adjusting to changes in relative price of outputs and inputs in the short run. Given that there is imperfect information available to farmers, it is likely that farmers may not make the full adjustment towards long-run optimal levels of their inputs within one year.

The Australian rural sector, with its long tradition in international trade, has experienced cost price squeeze in the 1980s and 1990s. The adjustment problem in Australian agriculture has been discussed extensively in the literature. The general trend of argument is that the rigidity in input markets puts adjustment pressure on farmers to respond to changes in output and input prices in the short run (see, for example, Musgrave, 1990; Gow and Stayner, 1995). Since the early work of Powell and Gruen (1967), a number of researchers have recognised the importance of accounting for adjustment costs in modelling production decisions of farmers to price changes in the short run

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(see, for example, McKay *et al.* (1980); Vincent *et al.*, 1980; Hall *et al.*, 1988; Fisher and Wall, 1990; Kokic *et al.*, 1993). These studies have specified farmer's production processes to be constrained by adjustment lags of inputs using essentially the static optimisation framework. Despite the fact that these studies have provided reasonable estimates of output supply and input demands, they have failed to provide adequately an estimate of the time path between the short run and long run.

From above, it is clear that the traditional approach, the static optimisation framework, is inappropriate for examining the structure of production and investment in the agricultural sector because it fails to account adequately for the direction of the adjustment path and the length of time of adjustment of quasi-fixed inputs (Kulatilaka, 1988; Wall and Fisher, 1988). The problem faced by Australian farmers and the lack of understanding of the extent of responsiveness of farmers to changing economic conditions was the motivating factor for undertaking this study. This of course constitutes the focus of this paper. The current paper extends the existing empirical work by specifying a dynamic model of Australian agricultural sector that incorporates adjustment costs using optimal intertemporal investment modelling framework. The model is used to analyse the nature and time path of adjustment of quasi-fixed inputs towards their long run optimal levels.

The rest of this paper is organised as follows. Section 2 discusses the optimal intertemporal investment model employed in the analysis. This section also describes the data employed in the analyses. Section 3 reports and discusses the empirical results. Section 4 presents some concluding remarks and suggestions for future research.

Model and Methods

Theoretical and Empirical Issues

The optimal intertemporal investment model proposed in this study is dictated by the formulation in the econometric literature. The use of optimal intertemporal investment models in agriculture is not new. The adaptation of the optimal intertemporal investment theory to examine a firm's production behaviour came into prominence with the seminal works of Eisner and Strotz (1963), Lucas (1967) and Gould (1968). This approach was popularised by Treadway (1969, 1970) and Mortensen (1973) and extended by McLaren and Cooper (1980) and Epstein (1981). The underlying principle of the optimal intertemporal investment theory is the adjustment cost hypothesis which is based on the premise that, in the short run, it is costly for the decision maker to adjust all inputs to their long-run equilibrium levels (Arrow, 1982).

The 1980s and 1990s have seen an emergence of a growing number of studies that have used variants of the optimal intertemporal investment model in the analysis of supply response and investment in agriculture. Some previous studies that employed the optimal intertemporal investment model include those by Epstein and Denny (1983), Taylor and Monson (1985), Lopez (1985), Vasavada and Chambers (1986), Howard and Shumway (1988), Vasavada and Ball (1988), Fernandez-Cornejo et al., (1992), and Krasachat and Coelli (1995), just to mention a few.

Now, consider a farmer who wishes to maximise profit subject to constraints. If the farmer faces adjustment costs, the intertemporal investment problem can be specified as follows:

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

subject to:

$$\dot{K} = I - \delta K,\ K(0) = K_0 > 0,\ \text{ and }\ Y = f(X, K, I) \qquad (2)$$

where $V(.)$ stands for the value of the farmer's productive assets over an infinite time horizon, p is price vector of outputs produced, w is 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 vector of physical investment in quasi-fixed inputs; r is a 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; K_0 is an initial endowment of K, $\dot{K}$ is the net investment in quasi-fixed inputs; and Y is a vector of outputs produced.

This study extends the value function in (1) by including a technical change variable as 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. This study assumes that farmers form expectations statically. That is, they use current price as a proxy for expected price. This assumption is consistent with the efficient market hypothesis proposed by Fama (1970), who argued that current price contains all relevant information about future price. Fama (1970) emphasises that, as economic conditions change, farmers recognising the inherent cost of acquiring information may formulate expectations rationally by continuously updating decisions based on readily accessible information such that the expected price becomes equal to the current price.

Assuming that the production function in Equation (1) satisfies all regularity conditions, then the value function in Equation (1) satisfies the Hamilton-Jacobi-Bellman (HJB) equation. This means that the static value function can be transformed to a dynamic setting. The HJB equation can be expressed as (Luh and Stefanou, 1991):

$$rV(p, w, q, \mathrm{k}, \mathrm{t}) = \max_{I}\left[\pi^{*}(p, w,\ K, \mathrm{I}, \mathrm{t}) - q'K + V_K'\ (p, w, q, K, \mathrm{t})\ (\mathrm{I}\text{-}\delta\mathrm{K})\right] + V_t(p, w, q, K, t) \qquad (3)$$

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

By invoking the Hotelling Lemma, the differential of Equation (3) with respect to input and output prices yield the conditional short-run optimal investment demand, output supply and variable input demand equations as follows:

Investment demand equation:

$$\dot{\mathrm{K}}_{\mathrm{q}} = V_{\mathrm{kq}}^{-1}\,(\mathrm{r}V_{\mathrm{q}} + \mathrm{K} - V_{tq}) \qquad (4a)$$

Supply equation:

$$rV_p = -K + V_{kp}\dot{K} + V_{tk} \tag{4b}$$

Variable input demand equation:

$$rV_w = -K + V_{kw}\dot{K} + V_{tk} \tag{4c}$$

By differentiating Equation (2), the optimised value function, with respect to K gives

$$rV_K = \pi_K - q - \delta V_K + V_{KK}\dot{K} + V_{tk} \tag{5}$$

and this yields

$$(r+\delta)\, V_K = \pi_K - q + \dot{V}_K \tag{6}$$

where

$$\dot{V}_K = V_{KK}\,\dot{K} + V_{tK} \tag{7}$$

The expression in Equation (7) states that the opportunity cost of investing 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, $\dot{V}_K$.

Before empirically estimating the system of equations it is important to determine the functional form characterising production technology. This study assumes production technology to be characterised by a generalised Leontief (GL) functional form. The GL function which satisfies the HJB equation, and can be specified as

$$\begin{aligned} rV(p,w,q,\mathrm{K},\mathrm{t}) = [p\,w']\mathrm{AK} + q\mathrm{B}^{-1}\mathrm{K} + [p^{0.5}\,w^{0.5}]\ \mathrm{E}\,q^{0.5} + [q^{0.5}\ \mathrm{F}\,q^{0.5}] \\ + [p^{0.5}w^{0.5'}]\ \mathrm{G}\,[p^{0.5}w^{0.5'}]' + \mathrm{TH}\,[pw'q] \end{aligned} \tag{8}$$

where the variables are as defined above, and A and E are *3x4* parameter matrices, G is a *3x3* parameter matrix, B is a *4x4* parameter matrix and H is a *1x7* parameter matrix.

Data sources and Description

This study utilises pooled cross-sectional and time-series data spanning the period 1979-1993. The data were obtained from farm surveys conducted by the Australian Bureau of Agricultural and Resource Economics (ABARE, 1994). The analyses consist of three categorisations: the pastoral zone, the wheat-sheep zone and the high-rainfall zone. The description of these zones are provided in Wall and Fisher (1988) and therefore not presented here. Data on price of outputs, variable input and quasi-fixed inputs were obtained from *Commodity Statistical Bulletin* 1994 (and earlier editions) (ABARE, 1994). It is important to emphasise that although the data does not cover the last decade, it certainly captures period of dramatic changes in economic conditions and institutional reforms. The results of this study may reflect perhaps the extreme response of farmers to external stimuli.

The major outputs produced in these agricultural zones considered. These are outputs of wool and wheat. Wool output is measured as total wool produced in kilo tonne greasy. Wheat output is measured as total wheat produced in kilo tonnes. One variable input was measured-materials and services. The data on materials and services include expenditure 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 have been obtained by dividing expenditure by an index of prices paid by farmers for materials and services.

Four quasi-fixed inputs were measured - labour, capital, sheep numbers and cattle numbers. Labour is treated as a fixed input and measured by the index of the 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). 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, which is reflected in the technical change variable. 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. Therefore, it was not included in the derivation of capital stock (see also, Fisher and Wall, 1990). Implicit quantity index for capital was derived by dividing the 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 opening numbers on the property. A constant discount rate used in this study is 0.06. Dummy variables were included in the model to capture variations in production technology across regions.

Results and Discussion

Table 1 presents estimates of the system of equations by the iterative non-linear seemingly unrelated least squares (ISURE) procedure in SHAZAM version 8.0 econometric package (White, 1997). The estimation uses the Davidson-Fletcher-Powell algorithm. The ISURE parameter estimates obtained are asymptotically equivalent to the Maximum Likelihood estimates at the point of convergence (Vasavada and Ball, 1988). The parameter estimates and asymptotic t-statistics of the ISURE method are available from the author upon request. Adopting the Baxter and Cragg (1970) measure of goodness-of-fit, the R^2 for system of equations were estimated to be close to 1.0 for all zones, suggesting a good fit.

The hypotheses of linear homogeneity and concavity in quasi-fixed inputs are maintained by the GL functional form used in this study (see, Howard & Shumway, 1988) and hence not tested. Symmetry was imposed on the estimated model to constrain the appropriate cross-partial derivatives to be the same (see Coxhead, 1992). Test for convexity in prices of the value function revealed that the value functions do not satisfy this condition. It is not surprising that the GL function failed to convexity assumption because it suffers from the violation of the curvature condition at all (or any) of the observation points (Lawrence, 1988). The result is not unique to this study. Other Australian studies, McKay et al. (1980, 1982) and Fisher and Wall (1990), and studies abroad, Howard and Shumway (1998) and Krasachat and Coelli (1995), have also concluded that their models failed the curvature condition. Following McKay et al. (1983), although a model does not satisfy the convexity assumption, the estimated results obtained from this study are quite satisfactory and are generally consistent with *a-priori* relationships. Hence, the results are discussed.

Since the focus of this study is to investigate dynamic adjustment in agricultural production in agricultural zones in Australia, we proceed to perform tests 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 $i \neq j$). Likelihood ratio tests have been performed to test these hypotheses.

Table 1. Chi-square statistics for tests of hypotheses of quasi-fixity of inputs across agricultural zones in Australia

Hypothesis	Pastoral Zone	Wheat-Sheep Zone	High-Rainfall Zone	Critical value
1. *Instantaneous adjustment*				
Labour	347.64[a]	277,646	8,156	$\chi^2_{4,0.05} = 9.49$
Capital	1,041.24	4,035.29	7,165.63	$\chi^2_{4,0.05} = 9.49$
Sheep numbers	397.43	3,123.33	1,141.62	$\chi^2_{4,0.05} = 9.49$
Cattle numbers	301.13	21,949.58	117.84	$\chi^2_{4,0.05} = 9.49$
2. *Independent adjustment*				
Labour and capital	7.27	1,976.58	386.96	$\chi^2_{2,0.05} = 5.99$
Labour and sheep numbers	5.25	296.14	407.41	$\chi^2_{2,0.05} = 5.99$
Labour and cattle numbers	37.95	567.56	55.32	$\chi^2_{2,0.05} = 5.99$
Capital and sheep numbers	86.30	36.93	16.97	$\chi^2_{2,0.05} = 5.99$
Capital and cattle numbers	24.92	155.44	156.0	$\chi^2_{2,0.05} = 5.99$
Sheep and cattle numbers	5.23	12.04	28.99	$\chi^2_{2,0.05} = 5.99$

Note: [a]Values are Chi-square statistics.

Table 2 reports tests for independent adjustment of quasi-fixed inputs. The results indicate that, with the exception of labour and sheep numbers and cattle and sheep numbers in the pastoral zone, the calculated likelihood ratio statistics exceed the critical value of 5.99 (5 percent significance level, 2 df) in all agricultural zones. The results indicate that with the exception of the labour-sheep and cattle-sheep input pairs in the pastoral zone, all other input pairs do adjust independently of each other towards the long-run optimal levels. The finding that labour and sheep adjust jointly is important and is consistent with production in Australian agriculture. In the pastoral zone, a large proportion of labour is used in the sheep industry for shearing hence it would be expected that investment decisions about labour and sheep numbers and between cattle and sheep numbers would be made jointly. This 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 zone. For the other agricultural zones, wheat-sheep and high-rainfall zones, the complex production mix, as discussed by Wall and Fisher (1988), does provide some support for the observed result of independent investment decisions on labour and cattle enterprises in these zones.

Table 2. Comparison of the rate of adjustment of quasi-fixed inputs across agricultural zones in Australia with studies abroad

Author and year	Input			
	Labour	Capital	Sheep numbers	Cattle numbers
This study				
Pastoral zone	-0.51	-0.28	-0.48	-0.45
Wheat-sheep zone	-0.07	-0.16	-0.79	-0.48
High-rainfall zone	-0.50	-0.24	-0.32	-0.73
Krasachat and Coelli (1995)	-0.34	-0.03	-	-
Howard and Shumway (1988)	-0.40	-	-	-0.04[a]
Vasavada and Chambers (1986)	-0.069	-0.118	-	-
Taylor and Monson (1985)	-	-0.55	-	-
Lopez (1985)	-	-0.43	-	-
Berndt et al. (1981)	-	-0.47	-	-
Tyrchniewicz and Schuh (1969)	-0.25	-	-	-

Note: [a]Estimated for cow numbers.

Next, we perform the test for 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). This test is performed with the assumption of independence maintained. Table 2 also reports the results of tests for instantaneous adjustment of inputs with independence maintained. For all agricultural zones, the null hypothesis of instantaneous adjustment is strongly rejected at the 5 percent 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 df. We conclude that labour, capital, sheep numbers and cattle numbers 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 production in agricultural zones in Australia.

Now, the estimated adjustment rates of quasi-fixed inputs of the accepted model provide relevant information on relative speed of adjustment of quasi-fixed 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-fixity of inputs adjust to their long-run optimal levels.

Table 2 reports the estimated rates of adjustment of quasi-fixed inputs. The estimated adjustment rates range from 0.28 for capital to 0.51 for labour in the pastoral zone, 0.07 for labour to 0.79 for sheep numbers in the wheat-sheep zone, and between 0.24 for capital and 0.73 for cattle numbers in the high-rainfall zone. The results indicate that adjustment of quasi-fixed inputs differ across agricultural zones in Australia. For example, while labour adjustment process is similar between the pastoral and high-rainfall zones, it differs considerably from that of the wheat-sheep zone. In addition, the rate of adjustment of sheep numbers differs across zones while that for cattle numbers appear to be similar for the pastoral zone and wheat-sheep zones. The adjustment of capital appears to differ across agricultural zones in Australia.

A comparison of the estimated adjustment rates of quasi-fixed inputs reported in this study with earlier studies is presented. The adjustment rate of labour (defined as family and hired labour) reported in this study are higher than 34 percent reported by Krasachat and Coelli (1995) for Thai agriculture. The adjustment rates of labour reported in this study are also higher than the 40 percent a year reported by Howard and Shumway (1988) for aggregate US dairy industry. The adjustment rates of capital in the agricultural zones are less than 47 percent reported by Berndt et al. (1981), 43 percent reported by Lopez (1985) and 55 percent reported by Taylor and Monson (1985). They are however higher than 12 percent reported by Vasavada and Chambers (1986) for the US agriculture and 3 percent reported by Krasachat and Coelli (1995) for Thai agriculture. There are no previous estimates of the adjustment rat of sheep numbers for comparison. The estimated rates of adjustment of cattle numbers reported in this study are higher than 4 percent reported by Howard and Shumway (1988) for cow numbers in United States dairy industry.

Concluding remarks

This study extends the static optimisation framework into a dynamic setting and applies this optimal intertemporal investment model to Australian data. Within this framework, the dynamic structure of investment in Australia's agricultural zones was explored. The results provide strong empirical evidence to indicate that quaxi-fixity is characteristic of production in agricultural zones. Labour, capital, sheep numbers and cattle numbers are slow to adjust towards their long run optimal levels in response to changes in relative price of outputs and inputs. The adjustment rates of quasi-fixed inputs of labour, capital, sheep numbers and cattle numbers appear to differ across agricultural zones in Australia. The investment in labour and sheep numbers and between sheep and cattle enterprises appear to be interdependent in the pastoral zone, suggesting that farmer's make decisions about investment in sheep and cattle industries jointly. The implication is that policies that influence the decision to invest in one of these enterprise is likely to influence the investment in the other. There is strong empirical evidence that farmer's adjustment behaviour is constrained by the sluggish nature of quasi-fixed inputs of labour, capital, sheep numbers, and cattle numbers used, emphasising the fact that adjustment problem is characteristic of agricultural production in Australia.

References

ABARE 1994. *Commodity Statistical Bulletin* 1994 (and earlier editions), Australian Bureau of Agricultural and Resource Economics, Project No. 1059, Canberra.

Arrow, K. J. 1982. Optimal Capital Adjustment, in: Arrow, K.J., Karlin, S. and Scarf, H., eds., *Studies in Applied Probability and Management Science*, Stanford University Press, Palo Alto, CA.

Baxter, N. and Cragg, J. 1970, Corporate Choice among Long-term Financing Instruments, *Review of Economics and Statistics*, 52, 225-35.

Berndt, E. R., Morrison, C. J. and Watkins, G. C. 1981. Dynamic Models of Energy Demand: An Assessment and Comparison, in Berndt, E.R. and Field, B.C., eds., *Modelling and Measuring Natural Resources Substitution*, by MIT Press, Cambridge, pp. 259-389.

Coxhead, I. A. 1992. Environment-Specific Rates and Biases of Technical Change in Agriculture, *American Journal of Agricultural Economics*, 74, 592-604

Eisner, R. and Strotz, R. H. 1963. Determinants of business investment: impacts of monetary policy, *Research Study Two*, Prentice-Hall, New York.

Epstein, L.G. 1981. Duality Theory and Functional Forms for Dynamic Factor Demands, *Review of Economics Studies*, 48, 81-95.

Epstein, L.G. and Denny, M.S. 1983. The Multivariate Flexible Accelerator Model: Its Empirical Restrictions and an Application to US Manufacturing, *Econometrica*, 51, 647-74.

Fama, E.F. 1970. Efficient Capital Markets: A review of Theory and Empirical Work, *Journal of Finance*, 25, 383-417.

Fernandez,-Cornejo, J., Gempeshaw II, C. M., Elterich, J. G. and Stefanou, S. E. 1992. Dynamic measures of scope and scale economies: an application to German agriculture, *American Journal of Agricultural Economics*, 74, 329-342.

Fisher, B. S. and Wall, C. A. 1990. Supply Response in the Australian Sheep Industry: A Profit Function Approach, *Australian Journal of Agricultural Economics*, 34, 147-166.

Gould, J. P. 1968. Adjustment costs in the theory of investment if the firm, *Review of Economic Studies*, 35, 47-55.

Gow, J. and Stayner, R. 1995. The Process of Farm Adjustment: A Critical Review, *Review of Marketing and Agricultural Economics*, 63, 272-283.

Hall, N., Frazer, L. and Purtill, A. 1988. *Supply Response in Broadacre Agriculture*, contributed paper to the 32nd Annual Conference of the Australian Agricultural and Resource Economics Society (AARES), Melbourne.

Howard, W. H. and Shumway, C. R. 1988. Dynamic Adjustment in the US Dairy Industry, *American Journal of Agricultural Economics*, 70, 837-847.

Hsu, S.H. and Chang, C.C. 1990. An Adjustment Cost Rationalisation of Asset Fixity Theory, *American Journal of Agricultural Economics*, 72, 288-308.

Kokic, P., Beare, S., Topp, V. and Tulpule, V. 1993. Australian Broadacre Agriculture: Forecasting Supply at the Farm Level, *ABARE Research Report 93.7*, AGPS, Canberra.

Krasachat, W. and Coelli, T. 1995. *Dynamics of Agricultural Production in Thailand*, contributed paper to the 39th Annual Conference of the Australian Agricultural Economics Society (AARES), Perth.

Kulatilaka, N. 1985. Tests on the Validity of Static Equilibrium Models, *Journal of Econometrics*, 28, 253-268.

Lawrence, D. 1988. Recent Developments in Applying Duality Theory, *Review of Marketing and Agricultural Economics*, 56, 375-382.

Lopez, R. E. 1985. Supply response and investment in the Canadian food processing industry, *American Journal of Agricultural Economics*, 62, 38-45.

Lucas, R. E. 1967. Adjustment costs and the theory of supply, *Journal of Political Economy*, 75, 321-334.

Luh, Y-H and Stefanou, S. E. 1991. Productivity growth in U.S. agriculture under dynamic adjustment, *American Journal of Agricultural Economics*, 73, 1116-1125.

Martin, W.J. and Alston, J.M. 1994. A Dual Approach to Evaluating Research Benefits in the Presence of Trade Distortions, *American Journal of Agricultural Economics*, 76, 26-35.

McKay, L., Lawrence, D. and Vlastuin C. 1980. Input Demand and Substitution in the Australian Sheep Industry, *Review of Marketing and Agricultural Economics*, 48, 63-81.

McKay, L., Lawrence, D. and Vlastuin, C. 1982. Production Flexibility and Technical Change in Australia's Wheat-Sheep Zone, *Review of Marketing and Agricultural Economics*, 50, 9-25.

McKay, L., Lawrence, D. and Vlastuin, C. 1983. "Profit, Output Supply, and Input Demand Functions for Multiproduct Firms: The Case of Australian Agriculture, *International Economic* Review, 24, 323-339.

McLaren, K.R. and Cooper, R.J. 1980. Intertemporal Duality: Application of the Theory of the Firm, *Econometrica*, 48, 1755-1762.

Mortensen, D. T. 1973. Generalised Costs of Adjustment and Dynamic Factor Demand Theory, *Econometrica,* 41, 657-665.

Musgrave, W. F. 1990. Rural Adjustment, in: Williams D.B., ed., *Agriculture in the Australian Economy*, Sydney University Press, Sydney

Powell, R.A. 1974. *Technological Change in Australian Agriculture: 1920 to 1969/70*, Ph.D. Thesis, University of New England, Armidale.

Powell, A. A. and Gruen, F. H. 1967. The C.E.T. Production Frontier and Estimates of Supply Response in Australian Agriculture, *The Economic Record*, vol. 47, pp. 553-566.

Taylor, T. G. and Monson, M. J. 1985. Dynamic Inputs Demands for Aggregate South-Eastern United States Agriculture, *Southern Journal of Agricultural Economics*, 17, 1-9.

Treadway, A. B. 1969. On rational entrepreneurial behaviour and the demand for investment, *Review of Economic Studies*, 36, 241-258.

Treadway, A.B. 1970. Adjustment Costs and Variable Inputs in the Theory of the Competitive Firm, *Journal of Economic Theory*, 2, 329-347.

Vasavada, U. and Chambers, R. G. 1986. Investment in US Agriculture, *American Journal of Agricultural Economics*, 68, 950-960.

Vasavada, U. and Ball, V. E. 1988. A Dynamic Adjustment Model for US Agriculture: 1948-79, *Agricultural Economics*, 70, 123-137.

Vincent, D. P., Dixon, P. B. and Powell, A. A. 1980. The Estimation of Supply Response in Australian Agriculture: The CRESH/CRETH Production System, *International Economic Review*, 21, 221-242.

Wall, C. A. and Fisher, B. S. 1988. Supply Response and the Theory of Production and Profit Functions, *Review of Marketing and Agricultural Economics*, 56, 383-404.

White, K. J. 1997, *SHAZAM- The Econometrics Computer Program Version 7.0*, McGraw Hill, New York.