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Induced Innovation in the High Rainfall Zone

John Martin*

The induced innovation hypothesis states that the direction of technical change is determined by changes in relative input prices acting as a "spur to invention". To determine the validity of this hypothesis for the High Rainfall Zone of the Australian sheep industry, technical change biases for five input categories were measured using time series data for the period 1952-53 to 1976-77. These biases were then related to relative changes in the price of these input categories. The biases were measured by the application of a translog cost function model and suggested that, in general, technical change has been biased toward the saving of labour and land, the using of livestock, and neutral in regard to capital, and possibly materials and services. Comparison of the ranking of the measured biases with that of the relative price changes indicated that all results, except those for capital, were in general conformity with the induced innovation hypothesis. Finally, the deficiencies of the model and implications of the results are discussed.

Introduction

The induced innovation hypothesis states that the direction (or bias) of technical change is determined by changes in relative input prices acting as a "spur to invention" (Hicks 1932, p. 124). Following Solow's (1957) apparent finding that technical change, rather than capital formation, was the major source of growth in the United States economy, attention was focused on the nature of technical change, with an increasing awareness that economic variables appeared to influence its rate and direction. Investigation of the induced innovation hypothesis was one manifestation of this interest (Binswanger 1978a).

Since technical change implies, *inter alia*, an increase in the efficiency of production, investigation of economic factors thought to influence the rate and direction of such change is of considerable importance, both for economic growth theory and research policy. The most direct application of the induced innovation hypothesis is in relation to research policy. If the nature of technologies adopted is influenced by changing relative input prices, the research effort may best be directed towards developing technologies which save the increasingly expensive inputs.

Empirical studies of technical change in Australian agriculture, reviewed below, have been largely directed towards measuring, rather than explaining, technical change. This is in part due to data and methodological limitations, and in part to the concept and definition of technical change itself. In view of the importance of Solow's (1957) work in the theoretical and empirical study of technical change, the relevant issues are summarized below.

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The concept of technical change adopted by Solow (1957, p. 313) is that of "any kind of shift" in the production function and is manifested by increased output from a given set of inputs. It is measured as a "residual" by identifying changes in output not attributable to changes in input quantities, typically capital and labour. The high importance of Solow's (1957) technical change residual was found to be affected by a number of factors. New technology may be incorporated ("embodied") in improved inputs (such as better machinery or, to a lesser extent, more skilled labour)¹. Hicks neutral technical change, leaving the marginal rate of substitution between inputs constant, is implicit in the Solow model. Non-neutral (biased) technical change may be capital-saving (labour-using), increasing the marginal product of capital to labour, or capital-using (labour-saving) which does the reverse. In addition, inputs not specified (such as weather) or non-conventional inputs (such as investment in education and research) or inputs misspecified, may also help "explain" the residual. Finally, the inherent unitary elasticity of factor substitution and imposed constant returns to scale in the Cobb-Douglas function underlying the Solow model may, *inter alia*, confuse substitution and scale effects with technical change.

In order to explain technical change, the Schumpeterian distinction between latent technology (invention) and that which is technically and economically feasible (innovation) is useful. The adoption of new technology by industry (diffusion) is the third step in technical change. The invention/innovation distinction, though blurred in practice, is of importance in the study of induced innovation, particularly since Hicks (1932) originally referred to changing relative factor prices as a "spur to *invention*" (p. 124, italics added).

In the induced innovation controversy begun in the 1960's including Salter (1960), Fellner (1961), Kennedy (1964), Samuelson (1965), Ahmad (1966), Nordhaus (1967), Hayami and Ruttan (1971) and Binswanger (1974 *a, b, c*, 1978 *a, b*), the need for a micro-economic foundation to "explain" the creation of new technical possibilities (invention) was of critical importance. Induced innovation models (notably Kennedy 1964 and Ahmad 1966) generally treated invention as exogenous, and only explained how changing relative input prices could determine the choice of technique (technology innovated). Using Edison's terminology, a useful, but oversimplified, analogy of the subsequent development of endogenous theories of technical change was to determine the role of "perspiration" (investment) as opposed to "inspiration" (faith, creativity, serendipity) in the creation of new technologies. This included a study of the factors thought to influence where the inventor directed his efforts, such as changing relative input prices, perceived profitability, market structure and institutional framework.² There is now general acceptance by economists of the role of investment in research and education in determining technical change (Heertje 1977). Efforts have been directed towards strengthening the micro-economic foundations (see for example, Binswanger 1974 *c*, 1978 *b, c*) to help quantify this role. The scope of this study is limited to an examination of the role of changing relative input prices in technologies adopted (innovation).

¹ Solow's (1960) vintage model incorporated technical change in improved capital inputs. See Denison (1962) and Jorgenson and Griliches (1967) for the initiation of the classic debate on embodiment, disembodiment and the residual.

² For a more detailed discussion of relevant issues see Kennedy and Thirwall (1972), Heertje (1977), Binswanger *et al* (1978) and, within agriculture, Peterson and Hayami (1977). Mansfield (1961, 1968, 1969, 1972) has made an important empirical contribution.

Previous Australian Studies

Measuring the growth in total factor productivity, defined as the ratio of output to the aggregate of all factor inputs, has formed a large component of the empirical studies of technical change in Australian agriculture.³ Herr (1964), Young (1971), McLean (1973), Powell (1974) and Hastings (1977) have utilized the Solow (1957) geometric productivity index, while Gutman (1955) directly used the Cobb-Douglas production function which underlies the Solow model. The arithmetic productivity index, introduced by Abramovitz (1956) and Kendrick (1961), and based on a linear production function was used by Hoogvliet (1973), who reported obtaining similar results from the Solow model. Saxon (1963) had earlier used an arbitrarily-weighted multifactor arithmetic productivity index. Results, ranging from an average annual compound growth rate in total factor productivity of -1.1 per cent to 3.96 per cent (Table 1) depend largely on the time period, degree of aggregation and data source. Productivity growth is measured as the residual growth in output not attributable to identified inputs. Identified inputs other than labour and capital used to "explain" the residual include weather and time (Young 1971) and research (Hastings 1977), while in the former study, Young also embodied an educational component in his labour variable.

The implicit neutral technical change and fixed elasticity of factor substitution in the Cobb-Douglas and linear production functions (respectively unity and infinity) are highly restrictive. The CES function, with constant and equal elasticities of substitution between pairs of inputs, is less restrictive, but gave variable results (Duncan 1972; Bates and Musgrave 1972; Te Kloot and Anderson 1977), being sensitive to data and model specification. More recently, Lawrence and McKay (1980) used a Tornqvist index which "can precisely reflect an arbitrary set of substitution possibilities at any given feasible point" (p. 48), to obtain an annual growth rate in total factor productivity in the Australian sheep industry from 1952-53 to 1976-77 of 2.9 per cent.

Models with variable elasticities of factor substitution are required to distinguish substitution effects from technical change, particularly given the non-unitary elasticities of factor substitution reported by Powell (1969), Duncan (1972), Bates and Musgrave (1972), Vincent (1977) and McKay, Lawrence and Vlastuin (1980). The derived demand model of Vincent (1977), and the CRESH/CRETH (Constant Ratio of Elasticities of Substitution, Homothetic/Constant Ratio of Elasticities of Transformation, Homothetic) model of Dixon, Vincent and Powell (1977) incorporate this flexibility, but have not been applied to the measurement of biased technical change in agriculture. The translog cost function model used in this study, which also permits variable elasticities of factor substitution, was first applied to Australian agriculture by McKay, Lawrence and Vlastuin (1980). Their findings suggested that technical change in the Australian sheep industry had been biased towards the saving of labour and land, and relatively capital, livestock and materials and services using. Unlike the earlier studies referred to, their estimates of the elasticity of substitution between capital and labour were found to be greater than, rather than less than, unity. More recently, McKay, Lawrence and Vlastuin (1982) fitted a

³ Other relevant studies include Young and Crestani (1973) who, *inter alia*, measured the productivity of purchased inputs, and Easter, Spillman and Scougall (1977) who updated Young's (1971) study and simulated the effects of various kinds of technical change using a linear programming model. Gruen *et al* (1968) and Throsby and Rutledge (1972) made unsuccessful attempts to construct aggregate production functions.

translog variable profit function to data for the Wheat-Sheep Zone of the Australian sheep industry encompassing three outputs and five inputs. Technical change was found to be strongly labour saving and capital using and relatively livestock and land saving. In addition, the study suggested that technical change had been biased in favour of crop production and against sheep and beef cattle.

Table 1: Estimated Rates of Total Factor Productivity Growth in Australian Agriculture

Author	Year of Study	Method ^a	Aggregation	Time Period	Growth Rate (per cent per annum)
Gutman, G. O. ..	1955	CD	AUST	1923-1947	-1.1
Saxon, E. A. ..	1963	ARITH	AUST	1937/38-1962/63	0.6
				1948/49-1962/63	1.1
Herr, McD. W. ..	1964	SOL	AUST	1922-1930	2.1
				1930-1940	0.7
				1940-1947	0.7
				1947-1955	0.8
				1955-1959	3.0
Young, R. ..	1971	SOL	AUST	1948/49-1967/68	1.9
Bates, W. and Musgrave, W. Duncan, R. ..	1972	CES	AUST	1920-1970	1.2
	1972	CES	N.S.W. Pastoral Zone.	1906-1967	1.31
Hoogvliet, W. ..	1973	ARITH	Pastoral Zone	1957/58-1970/71	0.9
			Wheat/S Zone		2.65
			High R Zone		2.88
McLean, I. ..	1973	SOL	VICTORIA	1870/71-1880/81	0.12
				1880/81-1890/91	0.10
				1890/91-1900/01	0.10
				1900/01-1910/11	0.33
Powell, R. ..	1974	SOL	AUST	1920/21-1929/30	-2.72
				1929/30-1939/40	3.96
				1939/40-1948/49	0.47
				1948/49-1959/60	0.47
				1959/60-1969/70	1.1
Hastings, T. ..	1977	SOL	AUST	1925/26-1969/70	1.52
Te Kloot, J. and Anderson, J. ..	1977	CES	Single Farm	1937-1970	-1.67
		CES	QLD		-1.10
		CES			-0.35
		CES			-0.26
		VES			-0.11
		VES			-1.18
		CD			-0.37
		TRANS			-0.51
		GPPF			-0.58
Lawrence, D. ..	1980	TORNQ	Pastoral Zone	1959/60-1976/77	3.1
			Wheat/S Zone		3.2
			High R Zone		3.0
Lawrence, D and McKay, L. ..	1980	TORNQ	AUST	1952/53-1976/77	2.9

^a CD: Cobb/Douglas; ARITH: Arithmetic Productivity Index; SOL: Solow Geometric Productivity Index; CES: Constant Elasticity of Substitution; VES: Variable Elasticity of Substitution; TRANS: Transcendental; TORNQ: Tornquist.

The only empirical study of Australian agriculture which has directly addressed the issue of the causes of technical change, apart from those studies using various variables to "explain" the Solow residual, is Fleming (1979).

Whilst not measuring technical change *per se*, Fleming tentatively concluded in his CES production function study of post-war Australian agriculture that the observed substitution of capital for both land and labour appeared to be facilitated by technical change. Given the nature of the factor price changes, results were consistent with the substitution predictions of neoclassical theory and the induced innovation hypothesis of technical change.

Methodology

The examination of induced innovation in the High Rainfall Zone of the Australian sheep industry was conducted by comparing measured technical change biases with movements in relative input prices. The translog cost function model developed by Binswanger (1974 *a, b*; 1978 *c, d*) and applied by McKay *et al* (1980) was used to measure input biases for five inputs. The main features of the model include its ability to allow variability in the elasticities of substitution between inputs in the multiple-input situation, and relative ease in estimation due to lower data requirements and utilization of ordinary multivariate regression techniques. Under relatively weak regularity conditions and assuming cost-minimization behaviour of producers, the production technology can be described by the cost function. Following McKay *et al* (1980), input-share estimating equations are specified by expressing the explanatory variables in terms of price ratios:

$$(1) S_L = b_L + b_{LL} \ln(w_L/w_M) + b_{LN} \ln(w_N/w_M) + b_{LV} \ln(w_V/w_M) + b_{LC} \ln(w_C/w_M) + b_{Lt} \ln t + e_1$$

$$(2) S_N = b_N + b_{NL} \ln(w_L/w_M) + b_{NN} \ln(w_N/w_M) + b_{NV} \ln(w_V/w_M) + b_{NC} \ln(w_C/w_M) + b_{Nt} \ln t + e_2$$

$$(3) S_V = b_V + b_{VL} \ln(w_L/w_M) + b_{VN} \ln(w_N/w_M) + b_{VV} \ln(w_V/w_M) + b_{VC} \ln(w_C/w_M) + b_{Vt} \ln t + e_3$$

$$(4) S_C = b_C + b_{CL} \ln(w_L/w_M) + b_{CN} \ln(w_N/w_M) + b_{CV} \ln(w_V/w_M) + b_{Cc} \ln(w_C/w_M) + b_{Ct} \ln t + e_4$$

where S_i = share of input i ,

b_i = constant terms,

b_{ij} = coefficients of price variables,

b_{it} = coefficients of technology variables,

w_i = price of input i ,

t = time and

$i, j = L$ (Labour), N (Land), C (Capital), V (Livestock), M (Materials and Services).

In the absence of a suitable index of technology, time (t) is incorporated as a proxy in the explanatory variables to allow for biased technical change. This procedure has been justified on the grounds that "when many discrete and almost random influences are aggregated, it is not unreasonable to suppose that aggregate technical change can be represented by a smooth time trend" (Ferguson 1969, p. 216) and is consistent with similar studies elsewhere Binswanger (1974 *a, b*), Nghiep (1979) and McKay *et al* (1980, 1982). Justification largely rests on the fact that although the link between aggregate production functions and their micro-level foundations is theoretically deficient, "empirical studies portraying technical change by a shifting macroeconomic production function do enrich our understanding of reality" (Heertje 1977, p. 171). Technical change resulting in increased output from a given set of inputs over time is

categorized as factor-augmenting.⁴ Since no quality adjustments in inputs were attempted, the technology index ($\ln t$) will reflect both disembodied technical change and errors due to not including embodied technical change.

The logarithmic form of the technology variable ($\ln t$) means that technical change is input-augmenting at an exponential rate and is therefore sensitive to the starting point and units adopted for the time variable. At higher numerical values of t , the technology index gives results approximating those from a linear technology variable. Given the emphasis here on the relative, rather than absolute, levels of the technology variables, the usual convention of integral increments from $t = 1$ to 25 for the 25 years 1952–53 to 1976–77 was adopted.

The b_{it} coefficients may be interpreted either as the rate of bias over the time period (assuming that the rate has remained constant), or as the average rate of bias over the time period. Interpretation of the sign of the coefficients is as follows:

- $b_{it} > 0$; technical change has been biased in being relatively input i -using,
- $b_{it} = 0$; technical change has been Hicks neutral,
- $b_{it} < 0$; technical change has been biased in being relatively input i -saving.

Technical change biases (B_i) can be calculated which measure the average annual percentage change in input share due to biased technical change over the period, assuming constant relative input prices. At constant relative input prices, there will be no change in input shares due to substitution. Hence incorporation of technical change in this manner theoretically enables technical change biases to be directly measured, and to separate the changes in input shares due to biased technical change from changes due to substitution.

The b_{it} coefficients were converted to measures of technical change bias (B_i) by the formula

$$B_i = \frac{b_{it} \times 100}{t \cdot S_i}$$

where

B_i is the percentage change per annum in the input share due to technical change over the period.

b_{it} is the change in the share of the input i , at constant relative input prices, as a result of a change in the technology index ($\ln t$).

S_i^* is the share of the input i at the commencement of the period. Because of the fluctuations in input-shares between years, the input-share at the commencement of the period (S_i^*) was taken as the average of the three years 1952–53 to 1954–55, rather than the share for 1952–53.

t is the time period considered.

Other approaches to measuring the direction of technical change, such as changes in output per unit of labour or alternative partial productivity indices, are unable to distinguish between input substitution (such as increased mechaniza-

⁴ This categorization is used by McKay *et al* (1982). Yotopoulos and Nugent (1976, p. 159), however, referred to factor augmentation in terms of quality improvements embodied in factor inputs.

tion) and technical change.⁵ Total factor productivities (geometric and arithmetic) implicitly assume neutral technical change. Physical partial production functions (e.g., the response curves of Heady and Dillon (1961)) can be used over time to help identify sources of technological improvement, such as Heady and Auer's (1966) study of yield increases due to variety, fertilizer and locality in United States field crop production. These micro-level studies can help confirm, refute or explain the macro-level findings, but in isolation are unable to determine the overall direction of bias at the aggregate level, where various types of new technology are being integrated.

To obtain a measure of the average annual percentage change in input prices (p_i) over the 25 year period (or 21 year sub-period), the logarithms of the input price indices (P_i) were regressed over time according to the formula:

$$\ln P_i = a + p_i t + e$$

where

P_i = price index of input i

t = time

p_i = annual rate of change in the input i price.

Relative price changes were determined by ranking the average annual price changes for the five inputs.

The examination of induced innovation consists of the comparison of the movements in relative input prices with the corresponding technical change biases. Ideally this should be a simultaneous process, but the inherent difficulties in measuring technical change biases meant that the two were estimated independently, then compared. Thus, given a ranking of input price changes such that $\Delta P_L > \Delta P_N > \Delta P_C > \Delta P_M > \Delta P_V$, the order of technical change biases predicted by the induced innovation hypothesis would be $B_L < B_N < B_C < B_M < B_V$.

Results and Discussion

The time-series data used in this study were developed initially by Lawrence and McKay (1980) from the Australian Sheep Industry Survey for the period 1952-53 to 1976-77. Data for the High Rainfall Zone were first presented by Lawrence (1980).

The four input-share equations (labour, land, livestock and capital) estimated from the Restricted Generalised Least Squares (RGLS) model, together with the materials and services equation derived from the homogeneity constraints, are presented in Tables 2 and 3. The former table relates to the sub-period 1952-53 to 1972-73, chosen because of the increased rate of inflation from 1973. The technical change biases are presented in Table 4, whilst Tables 5 and 6 present actual and estimated input shares over time. The data on which is based the measured changes in input prices, given in Table 7, are given in the Appendix. The results of the examination of induced innovation are presented in Table 8.

⁵ However, Binswanger *et al* (1978, Ch. 3) using the Hayami and Ruttan (1971) study, showed how to infer biased technical change in the two factor situation using the concepts of implied "necessary" and "critical" elasticities of substitution.

Table 2: Input Share Equations: RGLS Estimates,¹ 1952/53-1972/73

Input Share	Constant	Labour	Land	Livestock	Capital	Mat/Serv ³	Time	D.W. ⁴
S.		$b_{iL} \ln(W_L/W_M)$	$b_{iN} \ln(W_N/W_M)$	$b_{iV} \ln(W_V/W_M)$	$b_{iC} \ln(W_C/W_M)$	b_{iM}	b_u	
Labour ..	0.2778 ² (30.25)***	0.0374 (0.91) ^{n.s.}	-0.0713 (-6.11)***	-0.0552 (-3.89)***	-0.0330 (-1.04) ^{n.s.}	0.1221	-0.0089 (-1.84)*	1.40 ^{i, f}
Land ..	0.2032 (30.25)***	-0.0713 (-6.11)***	0.1154 (12.27)***	-0.0211 (-2.04)*	0.0216 (2.17)**	-0.0446	-0.0207 (-5.57)***	0.94 ^{i, f}
Livestock ..	0.1238 (11.69)**	-0.0552 (-3.89)***	-0.0211 (-2.04)*	0.0447 (2.00)*	-0.0251 (-2.36)**	0.0567	0.0256 (4.86)***	2.00 ^{n, n}
Capital ...	0.1284 (14.83)***	-0.0330 (-1.04) ^{n.s.}	0.0216 (2.17)**	-0.0251 (-2.36)**	-0.0420 (-1.11) ^{n.s.}	0.0785	0.0078 (1.71) ^{n.s.}	1.59 ^{i, f}
Mat/Serv ³ ..	0.2668	0.1221	-0.0446	0.0567	0.0785	-0.2127	-0.0038	

Notes:

¹ In the Restricted Generalized Least Squares model, symmetry restrictions are imposed: i.e., $b_{ij} = b_{ji}$ for all i, j .

² t -statistics in parentheses: n.s. = not significant; * = significant at 10% level; ** = significant at 5% level; *** = significant at 1% level.

³ Derived from homogeneity constraints $\sum_{j=1}^n b_{ij} = 0$, $\sum_{i=1}^n b_i = 1$, $\sum_{i=1}^n b_u = 0$.

⁴ D. W. values refer to Ordinary Least Squares (OLS) regression of individual equations. Superscripts refer to D. W. test at 5 per cent and 1 per cent respectively; i = inconclusive, n = no serial correlation.

Table 3: Input Share Equations: RGLS Estimates,¹ 1952/53-1976/77

Input Share S_i	Constant	Labour $b_{iL} \ln(W_L/W_A)$	Land $b_{iN} \ln(W_N/W_M)$	Livestock $b_{iV} \ln(W_V/W_M)$	Capital $b_{iC} \ln(W_C/W_M)$	Mat/Serv ³ b_{iU}	Time b_{it}	D.W. ⁴
Labour	0.2931 ² (29.56)***	0.0870 (2.69)**	-0.0346 (-3.73)***	-0.0521 (-6.25)***	-0.0596 (-1.95)*	0.0593	-0.0194 (-3.71)***	1.11 ^{t, i}
Land	0.2183 (23.28)***	-0.0346 (-3.73)***	0.1350 (12.24)***	-0.0567 (-7.00)***	0.0279 (3.36)***	-0.0716	-0.0271 (-5.46)***	0.80 ^{p, i}
Livestock	0.1091 (9.14)***	-0.0521 (-6.25)***	-0.0567 (-7.00)***	0.0788 (6.48)***	-0.0133 (-2.17)**	0.0433	0.0336 (5.94)***	1.34 ^{t, i}
Capital	0.1344 (16.29)***	-0.0596 (-1.95)*	0.0279 (3.36)***	-0.0133 (-2.17)**	-0.0201 (-0.58) ^{n.s.}	0.0651	0.0034 (0.76) ^{n.s.}	1.64 ^{t, i}
Mat/Serv ³	0.2451	0.0593	-0.0716	0.0433	0.0651	-0.0961	0.0095	

Notes:

¹ In the Restricted Generalized Least Squares model, symmetry restrictions are imposed: i.e., $b_{ij} = b_{ji}$ for all i, j .

² t -statistics in parentheses; n.s. = not significant; * = significant at 10% level; ** = significant at 5% level; *** = significant at 1% level.

³ Derived from homogeneity constraints $\sum_{j=1}^n b_{ij} = 0$, $\sum_{i=1}^n b_{ij} = 1$, $\sum_{i=1}^n b_{ii} = 0$.

⁴ D. W. values refer to Ordinary Least Squares (OLS) regression of individual equations. Superscripts refer to D.W. test at 5 per cent and 1 per cent respectively; $t =$ inconclusive, $p =$ positive serial correlation.

Table 4: Technical Change Biases, High Rainfall Zone

Input <i>i</i>	1952/53–1972/73	1952/53–1976/77
<i>b_u</i> Parameters		
Labour	–0.0089* ^a	–0.0194***
Land	–0.0207***	–0.0271***
Livestock	0.0256***	0.0336***
Capital	0.0078 n.s.	0.0034 n.s.
Mat/Serv	–0.0038	0.0095
<i>S_i*: Input Shares at Commencement of Period (%)^b</i>		
Labour	28.1	28.1
Land	16.2	16.2
Livestock	16.6	16.6
Capital	13.5	13.5
Mat/Serv	25.6	25.6
<i>B_i: Technical Change Biases (%)^c</i>		
Labour	–0.151	–0.276
Land	–0.608	–0.669
Livestock	0.734	0.810
Capital	0.275	0.101
Mat/Serv	–0.071	0.148

^a Level of significance: n.s. not significant; * Significant at 10%; *** Significant at 1%.

^b Average of 3 year period 1952/53 to 1954/55.

^c Interpreted as the average percentage change in input share due to technical change over the 21 and 25 years respectively, or the rate of change in input share due to technical change over the period, assuming a constant rate.

In satisfying the conditions of the model, it was found that monotonicity in prices held over the observed range of input prices. Although the condition that the matrix of partial elasticities be negative semi-definite (test of concavity of input prices) did not hold, the own price elasticities of input demand were negative, hence all input demand equations were downward sloping.

In the full-period results (Table 4), technical change has been, on average, land-saving at 0.67 per cent per annum and labour-saving at 0.28 per cent per annum. Technical change has been input-using for livestock, at 0.81 per cent per annum. A capital-using bias of 0.10 per cent per annum is indicated, although the b_{ct} parameter on which this estimate is based is not significantly different from zero. The statistical significance of the materials and services parameter was not determined, but an apparent input-using bias of 0.15 per cent per annum is suggested. In the sub-period analysis, all inputs are of a similar order and retain the same sign, except for the materials and services input which becomes input saving at a rate of 0.07 per cent per annum. Thus it appears from these results that decision-makers have introduced technologies that have been biased towards the saving of land and labour, the using of livestock, and neutral in regard to capital and possibly materials and services.

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Table 5: Input Shares, High Rainfall Zone, 1952/53-1972/73

Year	Labour Share (%)		Land Share (%)		Livestock Share (%)		Capital Share (%)		Mat/Serv Share (%)	
	Actual	Estimated	Actual	Estimated	Actual	Estimated	Actual	Estimated	Actual	Estimated
1952/53	29.2	29.4	16.8	17.8	15.2	14.2	13.4	13.5	25.4	25.1
1953/54	27.5	28.4	15.8	16.0	17.7	16.1	13.1	13.6	26.0	25.9
1954/55	27.6	28.0	16.1	15.7	16.9	16.7	13.9	13.9	25.5	25.7
1955/56	26.0	26.9	15.9	15.3	20.2	17.9	13.9	13.9	24.0	26.0
1956/57	25.4	25.9	16.6	16.0	18.7	18.3	13.8	14.1	25.5	25.8
1957/58	26.8	25.8	17.8	16.8	14.1	18.0	15.0	14.6	26.3	24.8
1958/59	27.4	26.4	17.9	16.8	14.5	17.3	15.9	14.8	24.4	24.7
1959/60	27.9	25.9	16.7	16.0	15.2	17.7	15.0	14.5	25.2	25.9
1960/61	24.8	23.5	18.0	18.1	17.6	18.0	14.7	14.5	25.0	26.0
1961/62	25.3	23.6	18.4	18.0	16.0	18.0	14.7	14.6	25.6	25.8
1962/63	24.6	23.7	17.5	18.0	17.6	17.9	14.2	14.8	26.2	25.5
1963/64	22.2	22.6	16.4	17.4	19.0	18.5	14.2	14.1	28.2	27.3
1964/65	20.9	21.7	16.5	17.9	21.0	18.6	13.9	14.0	27.7	27.7
1965/66	21.2	22.3	16.7	17.6	19.2	18.6	14.3	14.3	28.7	27.2
1966/67	21.3	22.0	16.1	17.0	18.9	19.3	14.1	14.2	29.6	27.5
1967/68	19.2	19.9	21.9	21.8	15.4	17.9	15.4	15.5	28.0	25.0
1968/69	19.4	19.4	21.5	21.9	18.3	17.8	14.9	15.2	25.9	25.7
1969/70	19.2	18.5	22.4	22.5	18.1	17.5	15.5	14.9	24.8	26.6
1970/71	19.1	19.5	22.5	22.5	18.2	16.7	16.5	15.1	23.7	26.2
1971/72	19.5	20.4	23.2	22.8	18.0	15.8	15.0	15.5	24.3	25.5
1972/73	18.6	19.3	22.7	21.1	18.2	17.1	13.2	14.5	27.4	28.0
At mean prices	..	22.4	..	18.7	..	18.2	..	14.8	..	25.9

Table 6: Input Shares, High Rainfall Zone, 1952/53-1976/77

Year	Labour Share (%)		Land Share (%)		Livestock Share (%)		Capital Share (%)		Mat/Serv Share (%)	
	Actual	Estimated	Actual	Estimated	Actual	Estimated	Actual	Estimated	Actual	Estimated
1952/53	29.2	30.2	16.8	18.2	15.2	13.5	13.4	13.8	25.4	24.3
1953/54	27.5	28.8	15.8	15.8	17.7	16.2	13.1	13.6	26.0	25.6
1954/55	27.6	27.9	16.1	15.6	16.9	16.8	13.9	13.8	25.5	25.9
1955/56	26.0	26.3	15.9	14.5	20.2	18.6	13.9	13.9	24.0	26.6
1956/57	25.4	25.2	16.6	15.1	18.7	19.0	13.8	14.2	25.5	26.4
1957/58	26.8	25.2	17.8	16.5	14.1	18.1	15.0	14.6	26.3	25.6
1958/59	27.4	25.6	17.9	17.1	14.5	17.1	15.9	14.6	24.4	25.6
1959/60	27.9	25.3	16.7	16.2	15.2	17.9	15.0	14.1	25.2	26.5
1960/61	24.8	23.3	18.0	18.2	17.6	18.0	14.7	14.5	25.0	26.0
1961/62	25.3	23.3	18.4	18.3	16.0	17.9	14.7	14.6	25.6	25.9
1962/63	24.6	23.4	17.5	18.4	17.6	17.8	14.2	14.7	26.2	25.8
1963/64	22.2	22.4	16.4	17.4	19.0	19.0	14.2	14.1	28.2	27.1
1964/65	20.9	21.7	16.5	17.9	21.0	19.1	13.9	14.1	27.7	27.1
1965/66	21.2	22.1	16.7	17.8	19.2	18.9	14.3	14.3	28.7	26.9
1966/67	21.3	21.7	16.1	16.6	18.9	20.1	14.1	14.2	29.6	27.4
1967/68	19.2	20.9	21.9	22.8	15.4	16.8	15.4	15.5	28.0	24.0
1968/69	19.4	20.5	21.5	22.9	18.3	16.8	14.9	15.3	25.9	24.5
1969/70	19.2	19.9	22.4	23.8	18.1	16.4	15.5	15.1	24.8	24.8
1970/71	19.1	20.6	22.5	24.4	18.2	15.2	16.5	15.1	23.7	24.6
1971/72	19.5	21.6	23.2	25.5	18.0	13.7	15.0	15.2	24.3	24.0
1972/73	18.6	20.5	22.7	22.8	18.2	16.3	13.2	14.4	27.4	26.1
1973/74	18.7	18.1	22.8	20.5	19.8	19.4	12.8	13.3	26.0	28.7
1974/75	24.9	23.6	29.7	27.0	8.1	10.3	13.1	14.5	24.3	24.5
1975/76	24.2	23.1	25.5	22.4	11.0	13.6	14.2	13.6	25.2	27.2
1976/77	23.7	22.8	25.4	25.2	12.2	12.0	14.5	13.8	24.2	26.3
At mean prices	..	22.5	..	20.8	..	16.3	..	14.3	..	26.0

Actual and estimated input shares, reported in Tables 5 and 6, indicate a general decline in the labour input share and a rise in land input share over the period. At mean prices, the relative importance of inputs is respectively materials and services (26.0 per cent), labour (22.5 per cent), land (20.8 per cent), livestock (16.3 per cent) and capital (14.3 per cent) for the full period. Comparison of the actual and estimated input shares provides some measure of the degree of goodness of fit of the estimating equations once cross equation restrictions are imposed.⁶ The correlation squared statistics between the actual and predicted values for the period to 1972/73 (1976/77) were labour 0.93 (0.85), land 0.91 (0.86), capital 0.58 (0.48) and livestock 0.13 (0.56). Results for livestock are affected by the substantial year to year fluctuations in prices (indicated by the regression results for the livestock price index in Table 7).

Table 7: Price Trends 1952/53–1976/77^a

Input	Time Coefficient ^{b,c} (π)	Constant	R ²
1952/53–1972/73			
Livestock	0.0137 (3.61)***	4.5997	0.37
Materials and Services	0.8167 (15.18)***	4.4728	0.92
Labour	0.0308 (28.00)***	4.3440	0.97
Capital	0.0432 (33.23)***	4.2416	0.98
Land	0.0717 (20.49)***	4.1135	0.95
1952/53–1976/77			
Livestock	0.0192 (4.17)***	4.5572	0.41
Materials and Services	0.0310 (7.75)***	4.3551	0.71
Labour	0.0492 (9.84)***	4.1928	0.80
Capital	0.0596 (13.24)***	4.1066	0.88
Land	0.0778 (24.31)***	4.0634	0.96

^a Results of equations $\ln \pi = a + \pi t + e$

^b t statistics in parentheses: *** significant at 1% level.

^c These coefficients represent annual trends.

The average annual changes in the input prices presented in Table 7 demonstrate considerable variation between inputs. For the period to 1972/73 (1976/77) price increases ranged from 1.4 per cent (1.9 per cent) for livestock to 7.2 per cent (7.8 per cent) for land. The higher values for the period to 1976/77 in part reflect the higher rate of inflation in the post 1972–73 period.

⁶ For the individual equations, the R² statistics for Ordinary Least Squares for the period to 1972/73 (1976/77) were respectively labour 0.96 (0.92), land 0.93 (0.92), livestock 0.58 (0.74) and capital 0.67 (0.60).

The examination of induced innovation adopted consists of relating the relative input price changes to the measured technical change biases as presented in Table 8. Given the nature of the relative price changes such that $\Delta p_N > \Delta p_C > \Delta p_L > \Delta p_M > \Delta p_V$, the order of technical change biases predicted by the induced innovation hypothesis would be $B_N < B_C < B_L < B_M < B_V$. All the inputs, except capital, correspond to the predicted pattern for both time periods. That is, the higher the rate of price increase, the more negative (input-saving) the bias. Thus the input with the highest increase in price (land) is accompanied by the most negative (input-saving) technical change bias, whilst the relative price decline of livestock is accompanied by input-using technical change.

Table 8: Examination of Induced Innovation

Input (<i>i</i>)	Input Price Change ($k_i \times 100$) (% per annum)	Technical Change Biases (B_i) (% per annum)
1952/53–1972/73		
Livestock	1.37	0.73
Materials and Services	1.67	–0.07
Labour	3.08	–0.15
Capital	4.32	0.28
Land	7.17	–0.61
1952/53–1976/77		
Livestock	1.92	0.81
Materials and Services	3.10	0.15
Labour	4.92	–0.28
Capital	5.92	0.10
Land	7.78	–0.67

Although a cause and effect relationship cannot be clearly established with this model, association of increasing (decreasing) relative input prices with input-saving (input-using) biases for land, labour, livestock and materials and services is consistent with the induced innovation hypothesis.

The major difficulty lies in the interpretation of the result for capital. The finding that despite increasing capital prices, technical change is neutral for this input rather than capital-saving, is similar to the result obtained by Binswanger for the machinery input in his analysis of United States agriculture. He explained this result in terms of non-neutral innovation possibilities;

“Innovation possibilities must have been machinery-using regardless of the role of factor prices in determining biases. Any price induced bias would have been machinery-saving, not machinery-using. If price induced biases are important, then the machinery-using bias would have been even larger in the absence of the rise in machinery prices.” (Binswanger 1974*b*, p. 975).

The explanation in terms of non-neutral innovation possibilities means, in effect, that factors other than changing relative input prices must be involved in the adoption of capital-intensive technologies, and that the induced innovation hypothesis is therefore insufficient to explain the direction of technical change biases.

This explanation implies that the decision-maker cannot freely select technologies on the basis of relative input price changes because there is a stronger force at work biasing the "innovation possibilities" (technologies) potentially available towards the saving or using of particular inputs. Thus capital-using technologies developed abroad in response to a set of input prices in which capital is relative cheaper may have been successfully transferred to Australia. It may also be possible that technologies made available to the agricultural sector in Australia may have been developed in response to conditions pertaining to other sectors of the Australian economy, such as the industrial sector. Such an explanation implies that the induced innovation hypothesis may be operative at a wider level, where technologies developed overseas or in other sectors pertain to relative input price levels in those countries or sectors.

Alternatively, given technologies available have been developed for Australian agricultural conditions, the capital-using bias may result from other influences outside the induced innovation hypothesis. These include an *ex post* response to reduced quantities of labour in an imperfect rural labour market, or the adoption of capital-using technologies as a result of other economic and non-economic factors, such as access to taxation concessions, prestige value and ready availability.

Although the results of this analysis provide qualified support for the induced innovation hypothesis, the results should, however, be interpreted with caution because of the conceptual, methodological and estimational problems inherent in the study. These problems may be summarized as:

- (i) the inability to establish a cause and effect relationship between movements in relative input prices and the corresponding technical change biases;
- (ii) the inability to include the effects of changes in technology on relative input prices;
- (iii) the inadequacy of incorporating technical change as a smooth time trend;
- (iv) the use of average movements in relative input prices and average measures of technical change; and
- (v) possible influence of serial correlation given the inconclusive results of the Durbin-Watson test for some inputs.

Whilst such problems necessitate caution in interpreting the results, the model adopted has the advantage of providing some estimate of technical change biases in the multiple-input situation and lessens the aggregation problem by focussing on one zone of one industry.

Conclusions

The results of the analysis provide general support for the hypothesis that changes in relative input prices affect the nature of technical change. Technical change in the High Rainfall Zone of the Australian Sheep Industry has been generally labour and land saving, livestock using, and neutral in regard to capital, and materials and services. Apart from capital, the sign and order of these results is as predicted by the induced innovation hypothesis given the measured changes in relative input prices. However, the result for capital, if confirmed, implies that factors other than relative input price changes have affected the nature of technologies adopted.

Until recently, it had been assumed that technical change was exogenous-given to, but not affected by, the economic system. The results presented here lend some empirical support to the view that technical change is, to some extent, endogenously determined. Changes in relative input prices do appear to be one aspect of these endogenous factors, but not the sole element.

There are, however, a number of deficiencies in the induced innovation hypothesis, principally its rather simplistic consideration of what is clearly a complex interrelationship between changes in relative input prices and the nature of technical change biases. Thus, the effect of technology on input prices is an influence likely to affect the relationship between input prices and technical change biases. While the state of the art has advanced sufficiently to enable studies such as this to be undertaken, the model adopted is, in essence, relatively simplistic. It is impossible to completely explain, or predict, the technical change process because of its very nature, which as Dewey suggests, "almost by definition involves the appearance of the unforeseen" (Dewey 1965, p. 140). Further work may usefully focus on the micro level, to determine what factors influence the decision-maker in his choice of technology.

In relation to the High Rainfall Zone of the Australian Sheep Industry, the result that technological innovation has been labour-saving is consistent with popular belief. The apparent evidence of land-saving technical change in Australian agriculture is less expected, but is likely to be more applicable to the High Rainfall Zone where land may be in short supply and often more competitive with urban development and other non-agricultural uses. The result for land is, however, consistent with the induced innovation hypothesis, in so far as land prices have increased relative to all other inputs.

Such results, if confirmed, have important implications for the direction of agricultural research. If technologies adopted in part reflect the changing input price environment, research may be profitably directed in areas which save the inputs which are becoming relatively more expensive. In fact, it appears from these results that the agricultural research effort has been successful in making available technologies which correspond to the changing input price environment, although the degree of success, in relation to their total agricultural research effort, cannot be determined here.

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Appendix Table A1: Tornqvist Input Price Indices: 1952/53-1976/77

Year	Labour Price Index	Land Price Index	Livestock Price Index	Capital Price Index	Mat/Serv Price Index	Total Input Price Index
1952-53 ..	81.927	72.315	96.436	72.238	90.421	82.606
1953-54 ..	85.341	72.446	103.824	72.208	89.707	84.437
1954-55 ..	85.165	74.443	98.023	74.968	89.096	84.193
1955-56 ..	85.822	77.967	112.400	81.440	92.876	89.108
1956-57 ..	89.693	89.657	120.505	90.193	98.589	96.183
1957-58 ..	93.108	100.207	109.041	94.003	101.651	98.723
1958-59 ..	95.201	100.207	92.465	98.361	100.389	97.389
1959-60 ..	100.000	100.000	100.000	100.000	100.000	100.000
1960-61 ..	101.122	125.215	114.809	108.064	101.993	108.443
1961-62 ..	104.751	130.062	112.595	112.253	104.860	111.179
1962-63 ..	104.736	129.881	106.537	112.594	104.437	110.057
1963-64 ..	104.873	126.346	120.479	112.348	99.590	110.596
1964-65 ..	110.971	141.396	132.038	118.987	102.970	118.186
1965-66 ..	116.405	145.181	128.509	124.725	109.152	122.027
1966-67 ..	120.831	146.844	145.893	128.581	114.218	128.478
1967-68 ..	124.690	227.213	129.421	133.470	117.502	139.456
1968-69 ..	128.393	234.026	132.915	139.892	117.640	142.890
1969-70 ..	132.104	250.456	134.933	149.450	115.818	147.121
1970-71 ..	137.481	252.390	116.634	159.344	118.988	147.073
1971-72 ..	147.106	266.215	100.351	168.961	123.578	149.493
1972-73 ..	160.689	262.288	141.396	177.678	129.340	164.302
1973-74 ..	195.218	308.138	252.641	216.828	146.476	209.306
1974-75 ..	276.127	428.098	113.559	308.733	196.275	244.910
1975-76 ..	306.606	376.868	158.053	361.777	225.318	265.543
1976-77 ..	348.890	494.320	163.717	396.256	239.161	303.055

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