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Pasture Improvement Adoption in South-Eastern New South Wales

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Pasture improvement is said to be the technology which has most influenced Australia's post-war agricultural production but little is known of the factors which have influenced the pasture adoption process. This paper describes an exploratory analysis of the determinants of pasture improvement adoption on the central and southern tablelands of New South Wales, one of Australia's foremost grazing areas. The objectives were to quantify the separate influences on pasture improvement adoption and to determine whether there has been change in the response to these influences over time. The results indicate that most of the variation in improved pasture levels since 1950 was explained by movements in farm prices and input costs. Other periodic influences were evident as were important geographic and temporal differences.

1. Introduction

Pasture improvement's status as an agricultural technology is promoted by the restrictive nature of Australia's grazing environment. Generally unreliable rainfall and infertile soils and the low grazing value of many indigenous grasses impose strict limitations on Australia's livestock production capacities. Arid pastoral areas comprise more than 80 per cent of occupied lands and nearly half the total land area. Relatively small areas have sufficient rainfall for pasture establishment and maintenance, and those which have are mainly confined to the temperate parts of eastern and southern Australia. While these areas constitute only 16 per cent of Australia's land base they carry more than 70 per cent of total livestock numbers.

The sown pasture revolution of the post-war period is regarded as the most important technological development in Australia's agricultural history (Donald 1965). Increased availability of inputs, finance and pasture research and extension resulted in the widespread introduction of improved pasture species throughout the temperate regions. In 20 years from 1950, the area of sown pastures quadrupled to 28 million hectares and nearly half of the increases in livestock populations and wool production at this time have been attributed to expanded improved pasture areas (Kinsman and McLennan 1961; Donald 1965). Pasture improvement was said to be more accepted by Australian primary producers than by those in other countries (Wilson 1968).

The strong growth trend in Australia's improved pasture areas slowed during the 1970's. By 1983, the area under sown pastures was estimated nationally to be 25.8 million hectares, a seven per cent area reduction over that of a decade earlier. Importantly there was evidence of a much greater decline in the improved pasture base of some of Australia's traditional grazing areas. Sown pasture areas on the central and southern tablelands of New South Wales fell 16 per cent between 1974 and 1984, and similar trends were evident elsewhere. These trends are symptomatic of a long-term decline in pasture improvement activity and livestock production (Table 1). Also, the practice of pasture improvement appears to have produced some undesirable side effects. Significant soil acidification problems in many traditional grazing areas have been partly attributed to the liberal fertilizer practices of previous years (in 1981, 1.8 million hectares in New South Wales were estimated to be affected by acid soils, Davey 1981).

A similar situation to that existing in the early post-war period is now evident for Australia's improved pasture resources. At that time the undoubted economic potential of pasture improvement was widely promoted to

* New South Wales Department of Agriculture, Orange. This paper has benefited from the suggestions of Garry Griffith and three anonymous referees. Remaining errors are the responsibility of the authors. This research was supported by a grant from the Wool Research Trust Fund on the recommendation of the Australian Wool Corporation.

Table 1: Livestock Production and Pasture Improvement Trends on the Central and Southern Tablelands of New South Wales; 1951-52 to 1983-84 [a]

Every two years as at 31/3	Sheep numbers (10^6)	Cattle numbers (10^3)	Wool Production (kt)	Area of sown grasses and clovers (10^3 ha)	Fertilizer usage (kt)
1951-52	7.1 (13.3)	255.4 (7.1)	22.3 (11.2)	285.4 (16.6)	26.0
1953-54	7.9 (13.2)	246.5 (6.9)	27.2 (11.0)	400.5 (16.4)	37.8
1955-56	7.6 (12.0)	255.5 (6.9)	29.8 (11.1)	542.1 (17.4)	43.8
1957-58	8.5 (13.2)	279.1 (7.5)	26.8 (11.4)	626.4 (16.7)	42.2
1959-60	9.2 (13.0)	276.7 (7.2)	37.0 (11.5)	627.6 (17.0)	44.1
1961-62	9.4 (13.5)	364.9 (8.3)	37.1 (12.6)	725.1 (17.9)	53.6
1963-64	9.2 (12.8)	421.3 (8.8)	37.2 (11.2)	746.5 (17.4)	67.0
1965-66	9.3 (15.2)	379.1 (9.1)	32.3 (13.3)	814.1 (18.5)	76.5
1967-68	10.3 (15.2)	418.4 (9.2)	38.5 (11.4)	816.8 (19.3)	67.2
1969-70	10.6 (14.7)	549.8 (9.8)	45.7 (13.4)	910.0 (20.3)	68.6
1971-72	9.7 (15.6)	786.6 (10.6)	36.9 (14.2)	1132.8 (22.7)	59.0
1973-74	8.5 (15.9)	962.8 (11.4)	31.4 (14.7)	1232.5 (20.8)	121.2
1975-76	8.6 (16.2)	1125.4 (12.3)	33.7 (15.5)	1218.4 (23.3)	28.1
1977-78	7.6 (15.9)	808.4 (11.0)	31.0 (13.4)	1185.3 (22.2)	63.0
1979-80	7.9 (16.3)	665.3 (10.9)	32.7 (13.6)	1305.4 (20.4)	117.5
1981-82	7.4 (15.1)	518.9 (9.6)	31.3 (14.5)	1089.4 (23.1)	54.1
1983-84	7.6 (14.9)	418.5 (8.3)	32.7 (14.2)	1033.0 (23.6)	25.2

[a] *Source:* ABS (1985); and previous issues.

(%) Proportions of State total.

Australian livestock producers and their rapid adoption response to the new pasture technology resulted in substantial economic benefits to the nation (Duncan 1972). The incidence of pasture improvement was reduced in many of Australia's major grazing areas over the 1970's and there are now examples of declining pasture productivity.

There has been little analysis of the pattern of adoption in pasture improvement in Australia (Duncan 1972, and Menz 1984, are two exceptions). This may partly be due to the difficulties in isolating a set of factors which offer a satisfactory explanation of pasture improvement activity over all time periods and regions. Movements in product prices, input costs and general economic trends are likely influences on pasture improvement decisions, while biological factors (topography, rainfall and soil fertility) are also important. These influences can be expected to vary over time and regions. The work of Menz (1984) highlights the difficulties in quantifying these relationships over large areas. In this study economic factors were found to be relatively unimportant determinants of pasture improvement adoption between 1950 and 1970. Although not proven, it was suggested that the rate of adoption of pasture improvement was likely to have become more sensitive to economic influences post 1971.

The purpose of this paper is to examine the determinants of pasture improvement adoption in one of Australia's traditional grazing areas since the early 1950's. In the absence of other related work, this is essentially an exploratory examination of the factors which have influenced the adoption of pasture improvement practices between regions and over time. The study considers two general propositions. The first is that the determinants of pasture improvement adoption are likely to have varied across the region because of environmental and other localized constraints. The second is that there has been considerable change in these influences over the period. A potential source of such change is movement in product prices and input costs. The general pattern of pasture improvement adoption is described in section 2 which also contains a review of the mainstream Australian economic studies of pasture improvement. Details of the study area, model specifications and data sources are given in section 3 while section 4 contains the estimation methods and results. A review section 5 discusses the implications of the results for pasture improvement activity in the 1980's.

2. Background

2.1 The Pattern of Adoption

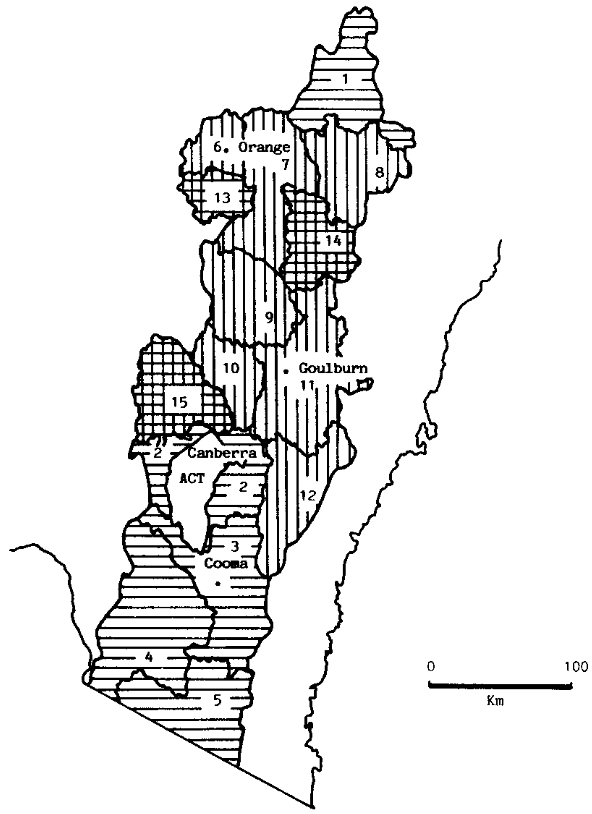
Menz's (1984) national analysis indicated a general S-shaped adoption pattern for pasture improvement comprising three phases. Prior to 1950 there was only a small area of improved pasture with the total area under sown species estimated to be below six million hectares. By 1970 the national area of improved pastures had increased to over 28 million hectares resulting from an annual increment of approximately one million hectares. These area increases were proportionally greater in the early years with the 1950's annual rate of growth being double that of the 1960's. Much of the expansion in improved pasture areas occurred in the more favourable climatic areas of south-eastern Australia. In the third phase, there was a significant slowing down in the rate of growth of area of improved pasture and then a decline in area over the 1970's with the total national area of sown pastures declining 12 per cent between 1970 and 1980.

2.2 Previous Australian Studies

Few other Australian agricultural technologies have received as many favourable economic assessments as pasture improvement. The rapid post-war increases in sown pasture areas were complemented by numerous economic studies of pasture improvement and pasture related issues. Neither the interest of economists in pasture improvement at this time nor the consistency of their findings is surprising. Because of the national importance of the grazing industries, improved pasture technology held the promise of major national benefits including increased livestock production and export market opportunities (Anon. 1953); higher farm returns (McConnell 1955; Gruen 1956*a*); greater production flexibility (Gruen 1960); increased demand for labour and other farm inputs (Waring and Jackson 1963); and lower product prices to domestic consumers (Gruen 1960). Favourable product price cycles, low inflation and a run of relatively good seasons to 1965 made pasture improvement an attractive low-risk farm investment. Pasture improvement was said to have the potential to raise farm incomes to a considerably greater extent than any alternative farm investment, including the purchase of additional land (Gruen 1959).

The potential economic benefits from pasture improvement received only passing reference in much of the earlier work which was more concerned with the benefits of improved animal nutrition and soil fertility, and the prevention of soil erosion. There was little analysis of the costs and returns from pasture improvement and profitability seemed to be a minor consideration. A change in emphasis occurred in the mid-1950's with the emergence of increasing cost-price pressures on the Australian livestock industries. Emphasis was given to pasture improvement's role in insulating producers against unfavourable economic trends through increased livestock productivity (McConnell 1955; Gruen 1956*b*; Gruen and Pearse 1958; Campbell and Shand 1958; Waring and Jackson 1963) and enterprise diversification (James 1962; Manderson 1966). The constraints to adoption were a focus of attention. Shortages of capital and superphosphate (Molnar 1951; Parish and Dillon 1956), machinery and managerial ability (Malikides and Waring 1967) resulted in slow adoption in the early years. The major constraints were the capital and time requirements of the investment whereby the producer could expect to be financially worse off for three to twelve years depending on individual objectives and circumstances (Gruen 1956*b*; Campbell and Shand 1958; Pearse 1963). Many producers were unable or unwilling to make commitments to long-term pasture improvement programmes (Waring and Muir 1961), even when gradual development was thought to be economically superior to rapid improvement over two to three years (Gruen 1959). However the income improving potential of pasture improvement remained unquestioned. Gruen (1959) concluded that investment returns to improving pastures were far greater than to any other avenue of farm development, and this was still the case 16 years later (Hoogvliet 1975).

Most previous analyses were concerned with the evaluation of pasture improvement's potential to permanently raise farm capital and income levels. A general conclusion might be that the continued prosperity of Australia's grazing industries was closely associated with the adoption of the new pasture technology. There is now evidence to support this conclusion (Duncan 1972; Love *et al.* 1982). To paraphrase Menz (1984), pasture improvement was a highly profitable farm technology in the immediate post-war years. It was responsible for the approximate doubling of net farm incomes, and was the dominant influence on



15–30%

1. Rylstone
2. Yarrowlumla
3. Cooma - Monaro
4. Snowy River
5. Bombala

30–40%

6. Cabonne (CT)
7. Evans
8. Lithgow
9. Crookwell
10. Gunning
11. Mulwaree
12. Tallaganda

40+%

13. Blayney
14. Oberon
15. Yass

Figure 1: Proportion of agricultural holdings pasture improved as at March 31, 1984: New South Wales central and southern tablelands

Table 2: Ten Year Average Variable Levels and Simple Production Ratios for Individual Shires in the Study Areas; 1974–75 to 1983–84[a]

LGA	Area of agric. holdings (10^3 ha)	Area of sown pastures (10^3 ha)	Proportion of holdings pasture improved (%)	Sheep numbers (10^3)	Sheep carried per ha holding	Wool production			Cattle numbers (10^3)
						total (kt)	per head (kg)	per ha (kg)	
Central Tablelands									
Blayney	141.75	72.77	51.3	506.06	3.6	1.98	3.9	14.0	65.39
Cabonne	108.44	38.89	35.9	276.49	2.5	1.08	3.9	10.0	35.93
Evans	319.57	118.09	37.0	747.31	2.3	3.19	4.3	10.0	69.19
Lithgow	126.99	41.98	33.1	160.06	1.3	0.60	3.7	4.7	41.53
Oberon	137.14	71.09	51.8	448.34	3.3	1.53	3.4	11.2	42.81
Rylstone	202.13	48.63	24.1	215.67	1.1	0.84	3.9	4.2	52.77
Southern Tablelands									
Bombala	245.67	69.46	28.3	595.86	2.4	2.60	4.4	10.6	42.32
Cooma–Monaro	338.31	60.44	17.9	475.39	1.4	2.05	4.3	6.1	39.33
Crookwell	306.96	125.52	40.9	1046.19	3.4	4.57	4.4	14.9	54.60
Gunning	179.43	73.65	41.0	546.46	3.0	2.26	4.1	12.6	23.83
Mulwaree	364.73	140.73	38.6	796.56	2.2	3.22	4.0	8.8	70.68
Tallaganda	202.55	65.63	32.4	197.73	1.0	0.81	4.1	4.0	68.43
Snowy River	292.82	74.95	25.6	559.78	1.9	2.64	4.7	9.0	42.02
Yarrowlumla	158.85	44.49	28.0	266.62	1.7	1.15	4.3	7.2	28.57
Yass	282.79	115.10	40.7	948.21	3.4	4.01	4.2	14.2	49.00

[a] *Source:* ABS (1985, and previous issues).

the returns to livestock production in those regions in which it could be feasibly implemented.

2.3 The Study Area

The study area comprised 15 shires in the central and southern tablelands of New South Wales[1]. This area covers approximately 58,000 square kilometres of which 64 per cent were classified agricultural holdings in 1984 (ABS 1985). The region has a history of livestock production (Table 1) and has highly variable rainfall (between 500 and 900 mm) and soil fertility. There are large areas of low rainfall and poor soils (*e.g.*, the eastern rain-shadow of the Snowy Mountains) in which pasture establishment is difficult. Other areas have had high levels of pasture improvement for many years (Figure 1). The proportion of individual areas of rural holdings under sown grasses and clovers averaged 35 per cent, with a range of 50 per cent (Oberon) to 20 per cent (Cooma–Monaro) in 1984 (Table 2).

These diverse characteristics make this region a good testing ground for a model of pasture improvement adoption. The region was disaggregated into seven sub-regions; the central and southern tablelands separately, and combined as the region; the Shires of Oberon and Rylstone on the central tablelands, and Gunning and Cooma–Monaro on the southern tablelands. Individual shires were selected on the basis of their pasture improvement experiences and where area changes due to periodic boundary shifts have been minimal. Oberon and Gunning Shires have had the highest levels of pasture improvement in their respective regions, whereas Rylstone and Cooma–Monaro have had the lowest. Different influences and constraints can be expected to have determined adoption of pasture improvement in these areas.

3. A Model of Pasture Improvement Adoption

It has been convention to consider pasture improvement as a farm investment requiring a high capital commitment to establishment and maintenance, and long periods to recover capital outlay (Gruen 1956*b*; Pearse 1963; Vere and Campbell 1984). Apart from the available land, the existing pasture stock is the farm resource which most limits livestock production potential (Freebairn 1973) and any attempt to permanently increase livestock output must first involve a decision to improve pasture availability and quality. This latter decision will be influenced by a range of factors which can be expected to have varying periodic impacts on producers' perceptions and expectations. In the study area economic and seasonal conditions have fluctuated widely over time, as has the flow of pasture technology through the introduction of new species, establishment methods and the increased availability of essential inputs such as fertilizers and pesticides. Changes in government policy regarding taxation concessions, fertilizer usage and subsidised farm development finance have also had periodic influence. Additional complexities are introduced by the lags between pasture improvement decisions and outcomes and unforeseen contingencies such as droughts, pests and weeds. It is therefore likely that many factors have influenced improved pasture stocks and that there have been important temporal and regional variations in these effects.

3.1 Model Specification

In the general specification, the stock of improved pastures in any period was considered to be a function of farm livestock prices, input costs, seasonal conditions, previous pasture improvement activity and fertilizer costs and applications. Other influences include the availability of relevant pasture technology and those government policies and concessions which relate to pasture improvement.

The dependent variable was defined as the area of sown grasses and clovers (sown perennial and annual pastures) within individual regions and shires as measured in the annual agricultural census of the Australian Bureau of Statistics. Fertilized native pastures and pure lucerne stands were excluded. This definition is consistent with the hypothesis that landholders desire an absolute area rather than a proportion of their properties under improved pastures. A problem with this definition is that the data do not indicate the relative proportions of improved perennial grasses to annual clovers and legumes. This distinction is important because establishment costs and pasture longevity are significantly greater for the grasses. An alternative specification of the dependent variable as the proportion of improved pastures in the available grazing area was rejected after testing.

[1]The Shires of Blayney, Cabonne, Evans, Lithgow, Oberon and Rylstone (central tablelands); and Bombala, Crookwell, Cooma–Monaro, Gunning, Mulwaree, Tallaganda, Snowy River, Yarrowlumla and Yass (southern tablelands).

Commodity prices and prospects can be expected to strongly influence pasture improvement decisions. Here, livestock returns are most relevant since crop production has historically been minimal in the study area (only four per cent of total agricultural area in 1983–84). Favourable livestock prices should encourage pasture improvement while adverse livestock markets act as disincentives. Several alternate livestock price variable specifications were considered. Both current and previous prices were included because of the highly cyclical nature of saleyard livestock prices and the inherent lags between pasture establishment and livestock output. Expected prices were also tested to represent the influence of anticipated future price movements on pasture improvement decisions. Following Freebairn (1973) a simple three-period arithmetic lag structure of the observed price data represented anticipated livestock profitability. Also specified were two price variables constructed from annual index data (BAE 1984). The first was an index of farm prices for wool, cattle, sheep and lambs, and the second was the former index deflated by an index of input costs.

Increases in input costs will adversely affect pasture improvement stocks through restricted input use and activity deferral. More important longer term effects will result from a continuation of these trends and lead to pasture area and productivity reductions. Input costs were included as an index of prices paid by producers for all equipment and supplies (1980–81 = 100) (BAE 1984). This index excluded fertilizer costs which were specified separately because of their previously noted influence on pasture improvement activity (Duncan 1972).

Previous pasture improvement activity will strongly influence current stocks since, once established, improved pastures cannot be readily removed in the short term. A lagged dependent variable was included to represent the carry-over effect of previous activity on current improved pasture levels.

Other specified variables included fertilizer applications and prices, seasonal conditions, pasture research and development and pasture related government policies and concessions. Fertilizer usage has at times been held to be synonymous with pasture improvement. Duncan (1972) specified superphosphate application to pastures as the dependent variable in his evaluation of pasture research. Some of the earlier studies of pasture improvement on the northern tablelands of New South Wales treated fertilizer usage in the same context (Waring and Muir 1961). This practice is not similarly regarded by pasture scientists operating in the study area (M. H. Campbell, pers. comm. 1986) and here, fertilizer usage has been separately specified as an explanatory variable. Prior examination of the partial correlation coefficients between the dependent and fertilizer variables for all areas supported this specification (they were all below 0.61). The fertilizer variable was defined as total superphosphate applications, converted to a single superphosphate equivalent. Seasonal conditions were represented by an index of annual rainfall recordings for each shire adjusted by a growth index incorporating light, temperature and moisture developed by Fitzpatrick and Nix (1970). Dummy variables represented specific events in the release of pasture technology, major herbicides and the introduction or removal of government policy relevant to pasture improvement. Examples of pasture technology included the introduction of improved perennial grass species from overseas and efficient aerial techniques for pasture establishment, both of which have been of major importance in the study area. Relevant government policy included concessional finance for pasture improvement, taxation concessions and the introduction and removal of the fertilizer bounty. A linear time trend (1950 = 1, *etc.*) was also included to account for those technological and other influences which were not explicitly considered *a priori.* This variable might also represent an adjustment lag in the adoption of pasture technology. Other related work (in a national context) determined a highly significant time trend impact in the adoption of sown pasture technology (Menz 1984).

Various shocks to the agricultural sector over the years indicate the likelihood of change in the structure of pasture improvement adoption over time. Some examples include the high levels of inflation, livestock price instability, credit squeezes and the general energy shortages which characterized the 1970's. These events can be expected to have exerted considerable influence on pasture improvement decisions and it is likely that the adoption relationships will have changed over the period. The likelihood of temporal change in these relationships is examined using a general regression coefficient stability test (following Chow 1960). This procedure is described below and the null hypothesis is that the coefficients were constant over the sample period and hence the adoption determinants have remained stable over time.

3.2 Data

All data are annual between 1951 and 1984. Average annual saleyard beef and lamb prices were for Homebush, Sydney while wool price was the average Australian greasy price for all wools. The livestock profitability and input price variables were constructed from annual index data (BAE 1984). The seasonal variable was derived from annual rainfall registrations, adjusted by the Fitzpatrick and Nix growth index.

3.3 Estimation Periods

The sample period covers the 33 years 1952 to 1984. It includes that period in which Australia's pasture improvement activity has been most pronounced and those in which it has declined. Two sub-samples were also examined and were determined from plots of the dependent and key independent variables (Figure 2). Improved pasture stocks increased steadily over the first 20 years of the sample period but declined over the late 1970's. Other variables exhibit similar trends. For example, input costs rose gradually up to 1970 and increased abruptly thereafter. The first sub-sample covers the 17 years 1952 to 1968. The second is between 1969 and 1984 during which the level of pasture improvement declined (this sub-sample is extended backward slightly to allow more degrees of freedom for the estimates). The sub-samples provide the basis for the structural change tests.

3.4 Methods

All functions were estimated by ordinary least squares regression. Autoregressive corrections using a maximum likelihood method were applied to those functions in which first order autocorrelation was evident. The estimates derived under this procedure were reported irrespective of the significance of the autoregressive parameter (rho). All reported estimates were preferred on the basis of their statistical properties and consistency with prior expectations.

The structural change test involves application of the sample period estimates to the two sub-samples and comparison of the error sums of squares utilizing an F-test. Evidence of parameter instability (Table 3) suggested re-estimation of the sample period functions incorporating additional explanatory variables. Those functions in which coefficient instability was evident were re-estimated with the inclusion of additional variables constructed from those variables which appeared to be potential change sources and the time trend (a commonly adopted procedure for dealing with structural change problems in linear models, Chavas 1983). One weakness of the test adopted here is that it is a test of the stability of the overall regression rather than of the individual coefficients. Here the potential change sources were identified from time period differences in the coefficient levels for the relevant variables (these were essentially input costs and product prices).

4. Results

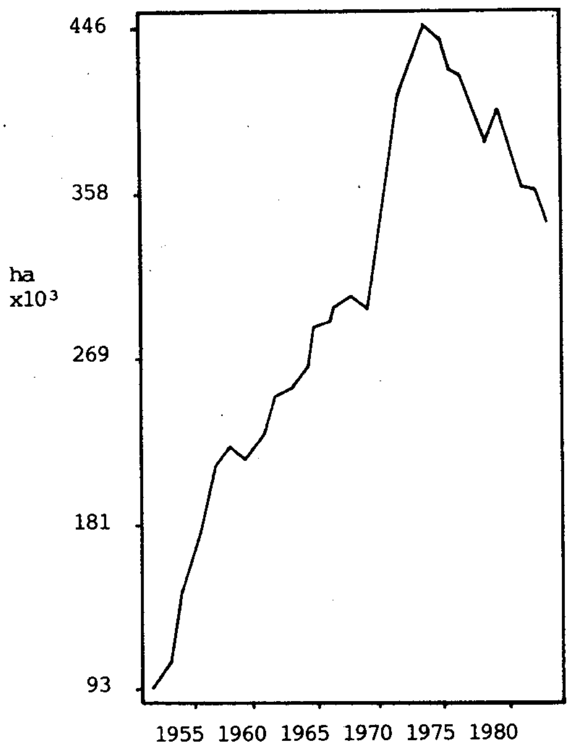
Three sets of estimates representing the regions and shires previously described are reported. Equations (1) to (7) are the preferred estimates for the whole sample period (Table 3), while equations (8) to (14) and (15) to (21) are the preferred estimates for the first and second sub-samples respectively (Tables 4 and 5).

The preferred estimates for the whole sample period indicate the absence of a common set of factors which offer a satisfactory explanation of pasture improvement adoption over all areas. Most functions have significant input cost and farm livestock price imp ts and all display a strong pasture stock carry-over effect. A trend influence is evident throughout but a response in improved pasture levels to pasture-relevant technology and policy could not be determined in any function. Noteworthy is the strong fertilizer effect in Gunning Shire as the southern areas have a greater incidence of low fertility soils than other parts of the study area. Also the influence of seasonal conditions on pasture improvement decisions in Cooma-Monaro Shire is an apparent reflection of the relatively low annual rainfall of much of the Monaro area. The general strength and direction of all estimates are consistent with expectations although the technology and policy dummies were expected to have some importance following Duncan (1972).

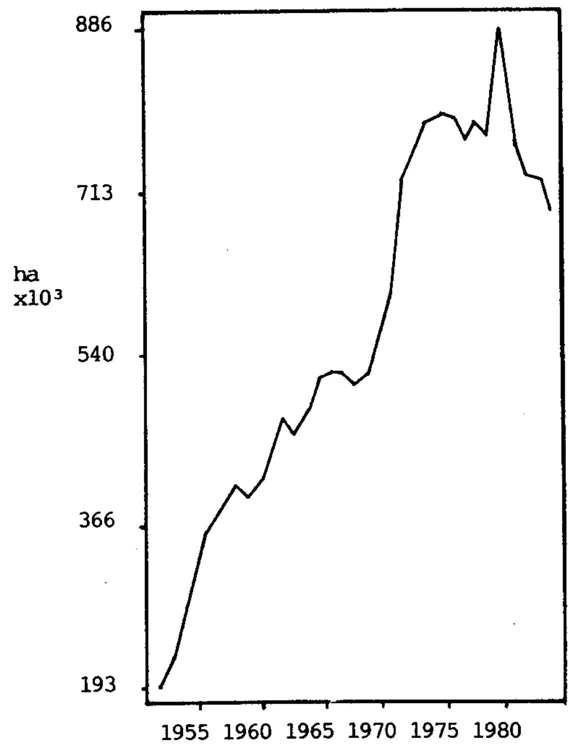
The coefficient stability tests provide strong evidence of structural change in pasture improvement adoption in all areas except Rylstone Shire.[2] Re-estimation incorporating various linear time varying parameters (Table 6) produced comparable results to the sample period functions although the coefficient levels

[2] Coefficient instability due to model misspecification appears to be unlikely as the estimated functions are consistent with expectations and are statistically sound.

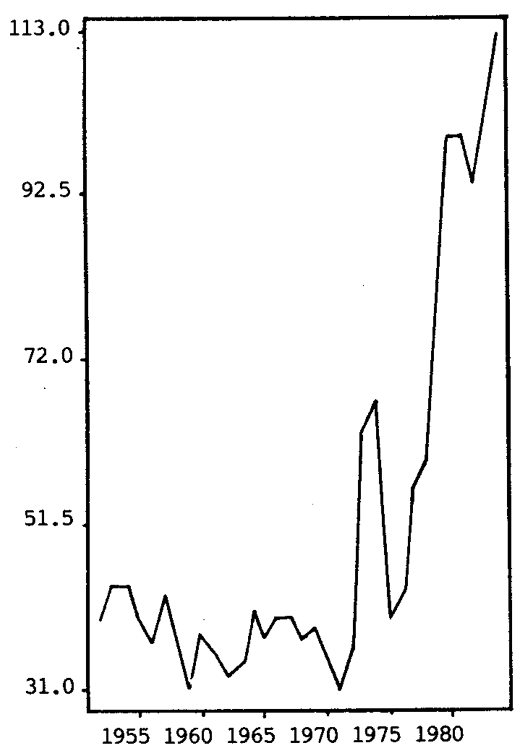
Figure 2—Plots of Major Variables, 1952–84



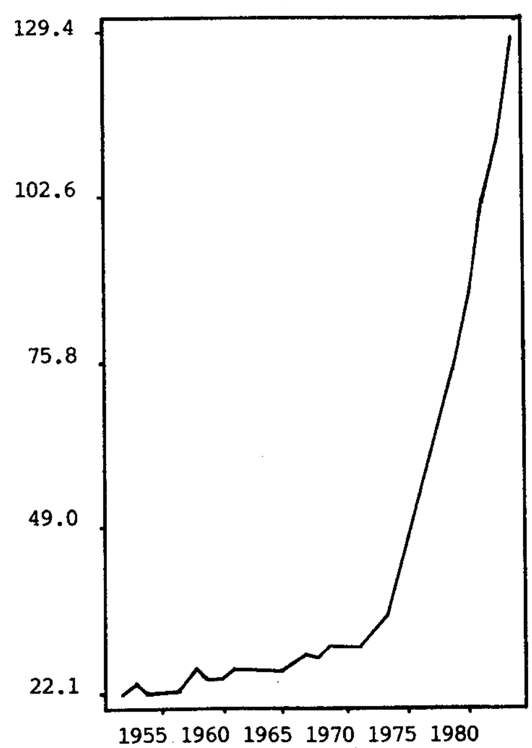
Area of sown grasses and clovers on the Central Tablelands.



Area of sown grasses and clovers on the Southern Tablelands.



Index of prices received by farmers for livestock products.



Index of prices paid by farmers for equipment and supplies.

Table 3: Equation Definitions and Initial Estimation Results for the Sample Period, 1952 to 1984

Dependent Variable	Equation Estimates[a]	$\bar{R}^2$	h	rho	Chow test
Area of improved pastures in—					
1. Total Tablelands:	TSGC = 99.37 + 0.73 LDV + 11.98 T + 1.78 INC − 3.49 CSTS	0.98	0.051	−0.08	19.18***
	(2.62) (6.77) (2.64) (1.87) (−3.52)			(−0.43)	
2. Southern Tablelands:	SSGC = 56.89 + 0.73 LDV + 7.52 T + 1.39 INC − 2.29 CSTS	0.98	0.106	−0.19	23.69***
	(2.20) (6.49) (2.54) (1.98) (−3.28)			(−1.04)	
3. Central Tablelands:	CSGC = 50.52 + 0.70 LDV + 4.65 T + 0.22 PBF − 1.16 CSTS	0.96	−0.104	0.33	6.77***
	(3.31) (5.27) (2.15) (1.37) (−3.87)			(1.89)	
4. Oberon Shire:	OSGC = 11.33 + 0.57 LDV + 1.17 T + 0.07 INC − 0.26 CSTS	0.97	0.043	0.17	9.43***
	(3.43) (4.44) (3.28) (1.13) (−3.71)			(0.93)	
5. Rylstone Shire:	RSGC = 1.89 + 0.99 LDV + 0.06 PBF1 − 0.10 CSTS	0.98	−0.286	−0.20	2.49
	(2.06) (28.27) (2.84) (−3.66)			(−1.11)	
6. Gunning Shire:	GSGC = 4.23 + 0.46 LDV + 1.70 T + 0.02 PWL1 + 0.001 GSF − 0.28 CSTS	0.98	−0.207		19.35***
	(1.82) (3.38) (3.70) (1.12) (2.00) (−3.56)				
7. Cooma-Monaro Shire:	MSGC = −1.59 + 0.65 LDV + 0.63 T + 0.15 PLB + 0.72 SEAS − 0.20 CSTS	0.98	0.126	0.36	14.62***
	(−0.53) (6.56) (3.02) (3.45) (2.67) (−3.95)			(−2.03)	

Notes: t values in ( ); *** significant at 99% confidence level; N = 33.

[a] Independent variables are defined in Appendix 1.

Table 4: Equation Definitions and Estimation Results for the First Sub-sample Period, 1952 to 1968

Dependent Variable	Equation Estimates[a]	$\bar{R}^2$	h	DW	rho
Area of improved pastures in—					
8. Total Tablelands:	TSGC = 533.75 + 0.99 LDV + 1.70 PBF1 − 4.39 PFZ1 − 18.07 CSTS	0.99	−0.18		−0.24
	(3.53) (16.49) (1.64) (−2.28) (−2.60)				(−0.85)
9. Southern Tablelands:	SSGC = 167.96 + 0.97 LDV + 1.50 PLB + 13.59 DUM2 − 8.30 CSTS	0.99	−0.26		−0.18
	(2.02) (14.05) (2.21) (1.21) (−1.96)				(−0.68)
10. Central Tablelands:	CSGC = 103.34 + 0.99 LDV + 0.93 PLB + 8.47 DUM2 − 5.67 CSTS	0.99	−0.62		−0.42
	(2.77) (19.84) (3.46) (1.97) (−2.99)				(−1.65)
11. Oberon Shire:	OSGC = 25.86 + 0.79 LDV + 0.79 T + 0.11 PLB − 1.14 CSTS	0.98	0.074		
	(2.20) (4.58) (1.80) (1.46) (−2.06)				
12. Rylstone Shire:	RSGC = 13.95 + 1.69 T + 0.16 PLB1 − 0.73 CSTS	0.94		1.92	−0.05
	(0.96) (6.04) (1.77) (−1.02)				(−0.17)
13. Gunning Shire:	GSGC = 11.22 + 0.97 LDV + 0.10 PLB + 2.44 DUM2 − 0.53 CSTS	0.99	−0.72		−0.59
	(1.33) (14.52) (2.10) (2.97) (−1.30)				(−2.68)
14. Cooma-Monaro Shire:	MSGC = 22.67 + 0.92 LDV + 0.22 PLB + 2.55 DUM2 − 1.18 CSTS	0.98	−0.49		−0.32
	(2.13) (12.59) (2.60) (1.86) (−2.36)				(−1.15)

Notes: t values in ( ); N = 17.

[a] Independent variables are defined in Appendix 1.

of the substituted variables were reduced. It appears that the major factors contributing to change in the adoption of pasture improvement practices have been movements in input costs and saleyard prices for beef and lamb. The problem of potentially harmful multicollinearity introduced through these constructed variables should be recognized (Maddala 1977).

The sub-sample estimates reveal response patterns similar to those of the sample period but with several important differences. Current and lagged farm prices (notably for lamb) had a more consistent impact on pasture improvement decisions between 1950 and 1970 than in the other two periods. The farm cost inflation of the 1970's was a powerful disincentive to pasture improvement activity in all areas. The results highlight the adverse changes in the cost-price structures for livestock production over the sample period. Product price effects on pasture improvement decisions were generally stronger prior to 1970 than in subsequent years when farm costs were of greater significance. These trends are evident from the regularly published "terms-of-trade" indices for livestock producers. The dummy variable impacts in four of the first sub-sample functions demonstrate the importance of effective herbicides in pasture improvement programmes in this region. Perennial weeds (such as serrated tussock) have long been a major economic problem on the tablelands and large areas have been successfully controlled under pasture improvement utilizing herbicides (Vere and Campbell 1984). The strong policy dummy effect in equation 17 suggests that pasture improvement on the central tablelands has been facilitated by government concessions. A further aspect of four of the third set of functions was the much reduced carry-over effect of previous pasture activity.

In overview, most of the estimated functions display sound statistical properties. All functions (except 18) have sets of variables which explain more than 90 per cent of annual variations in improved pasture stocks while the size, significance and direction of the coefficient estimates are consistent with prior expectations and economic behaviour. These results demonstrate the value of a disaggregated approach in the modelling of adoption response for agricultural technology such as pasture improvement. Previous national analysis has offered little explanation of this adoption pattern and it is likely that the use of aggregated data has obscured important characteristics and developments which have influenced pasture improvement decisions within specific areas. Further, important technological and institutional changes have taken place which have had a greater impact at the regional level. An example is the development of efficient aerial pasture establishment techniques which have enabled the pasture improvement of vast areas of non-arable country in south-eastern Australia.

5. Review

Pasture improvement adoption on the central and southern tablelands of New South Wales has followed a similar pattern to that determined by Menz (1984) for Australia. The steady growth in improved pasture areas between 1950 and 1970 levelled out over the 1970's and has since declined. This analysis has identified the main determinants of pasture improvement activity and has provided some evidence of change in the impacts of these influences over time.

The general result is that a range of factors has determined the adoption of pasture improvement across this region over the past 35 years. While no single combination of factors satisfactorily explains the adoption process over all areas and time periods, the influence of farm costs and livestock product prices has pervaded pasture improvement decisions. Evidence of strong economic influences on pasture improvement activity over all three periods contrasts the national findings of Menz (1984).

These results contrast two of Duncan's (1972) main conclusions; first, that the post-war upsurge in pasture improvement activity was due more to the release and adoption of new research than to favourable price cycles and, second, that fertilizer usage reflects producers' desires to raise or lower improved pasture stocks (the validity of these two findings is not disputed as they are consistent with the prior expectations of the present study). The need for the improved incorporation of technology flows is acknowledged as this analysis has been unable to determine any technology influence in improved pasture stocks despite its undoubted importance in the study area over the years. It appears that an alternative method of incorporating technology to the dummy variable approach adopted here may produce the expected results (although this approach had been successful in Duncan's 1972 study). The common practice of using a time trend as a technology proxy was felt to be inappropriate

Table 5: Equation Definitions and Estimation Results for the Second Sub-sample Period, 1969 to 1984

Dependent Variable	Equation Estimates[a]	$\bar{R}^2$	h	DW	rho
Area of improved pastures in—					
15. Total Tablelands:	TSGC = −450.51 + 0.28 LDV + 69.21 T + 1.46 INC − 10.32 CSTS	0.97	−0.42		−0.38
	(−2.22) (1.62) (3.54) (1.83) (−4.36)				(−1.44)
16. Southern Tablelands:	SSGC = −590.67 + 69.55 T + 0.38 PBF − 2.00 PFZ1 − 7.02 CSTS	0.98		2.40	−0.42
	(−6.01) (12.63) (1.27) (−1.80) (−3.97)				(−1.63)
17. Central Tablelands:	CSGC = −158.78 + 0.40 LDV + 21.04 T + 31.94 DUM3 − 2.76 CSTS	0.97	0.06		−0.27
	(−1.95) (2.32) (2.90) (2.86) (−3.05)				(−0.89)
18. Oberon Shire:	OSGC = − 36.42 + 6.00 T + 2.58 DUM3 − 0.82 CSTS	0.75		1.84	0.16
	(−2.44) (8.22) (0.91) (−9.05)				(0.56)
19. Rylstone Shire:	RSGC = 2.44 + 0.99 LDV + 0.07 PBF1 − 0.12 CSTS	0.92	−0.12		−0.25
	(0.51) (8.93) (2.45) (−3.08)				(−0.90)
20. Gunning Shire:	GSGC = − 25.81 + 0.24 LDV + 4.50 T + 0.06 PBF − 0.68 CSTS	0.94	0.38		−0.31
	(−1.77) (1.15) (3.22) (1.84) (−3.63)				(−1.16)
21. Cooma-Monaro Shire:	MSGC = − 20.25 + 0.48 LDV + 2.09 T + 0.10 PLB + 0.91 SEAS −0.33 CSTS	0.97	−0.98		−0.61
	(−1.53) (2.80) (1.89) (2.32) (2.46) (−2.78)				(−2.78)

Notes: t values in ( ); N = 16.

[a] Independent variables are defined in Appendix 1.

Table 6: Equation Definitions and Re-estimates of Sample Period Functions; 1952 to 1984

Dependent Variable	Equation Estimates[a]	$\bar{R}^2$	h	rho
Area of improved pastures in—				
22. Total Tablelands:	TSGC = 42.73 + 0.65 LDV + 16.35 T + 1.75 INC − 0.11 LTVA	0.98	−0.086	
	(0.94) (5.40) (3.02) (1.79) (−3.48)			
23. Southern Tablelands:	SSGC = 15.17 + 0.66 LDV + 10.05 T + 1.47 INC − 0.07 LTVA	0.98	0.087	−0.16
	(0.48) (5.55) (3.00) (2.07) (−3.40)			(−0.85)
24. Central Tablelands:	CSGC = 56.31 + 0.74 LDV + 3.79 T + 0.01 LTVC − 1.24 CSTS	0.97	−0.028	0.28
	(4.36) (5.89) (1.81) (1.76) (−4.14)			(1.56)
25. Oberon Shire:	OSGC = 9.83 + 0.28 LDV + 2.08 T + 0.07 INC − 0.01 LTVA	0.90	0.277	0.49
	(2.48) (1.70) (4.34) (1.24) (−4.43)			(3.08)
26. Gunning Shire:	GSGC = −1.63 + 0.35 LDV + 2.15 T + 0.02 PWL1 + 0.001 GSF − 0.01 LTVA	0.98	0.164	
	(−0.57) (2.46) (4.21) (1.28) (2.09) (−4.04)			
27. Cooma-Monaro Shire:	MSGC = 5.59 + 0.66 LDV + 0.40 T + 0.01 LTVD + 0.64 SEAS − 0.21 CSTS	0.97	0.171	−0.30
	(1.80) (6.30) (1.78) (2.77) (2.26) (−3.34)			(−1.64)

Notes: t values in ( ); N = 33.

[a] Independent variables are defined in Appendix 1.

in this instance. Further, a response to fertilizer usage could only be determined in equation (6) although lagged fertilizer price effects were evident in equations (8) and (16). This result suggests that overall, improved pasture levels are insensitive to fertilizer applications. An alternate interpretation might be that fertilizers are mainly used to maintain existing pasture stocks (to prevent or slow down pasture degeneration) rather than to alter their levels. Recent trends partially confirm Duncan's conclusions. With the exception of 1979–80, fertilizer usage has declined substantially since 1975 and there has been a corresponding reduction in improved pasture areas throughout the tablelands (Table 1). However the results of this analysis indicate that improved pasture reductions are due to movements in factors other than fertilizer usage. Fertilizer usage habits have changed substantially since the time of Duncan's study. Certainly his observation that the costs of improved pasture maintenance include "... the *ad infinitum* annual application of one hundredweight of superphosphate" is no longer the case on most tableland properties.[3]

Evidence of change in the structure of pasture improvement adoption indicates a changing response to pasture improvement incentives over time. While this analysis has been unable to completely isolate the sources of such change, it appears most likely to have been due to the adverse long-term movements in the livestock producer's farm cost-price structure of recent times. This change has potentially important implications for those government and other policies which affect pasture improvement decisions. For example, the pre-1972 taxation laws allowed an immediate deductibility of various capital expenditure items including land clearing, soil conservation and pasture improvement (Davis 1974). These concessions were a strong incentive to farm development and their removal has reduced the attraction of pasture improvement as an on-farm investment. At the state level, government subsidised finance provisions for pasture improvement and related activities have drawn criticism as being too restrictive for present-day needs (such finance is available through the various New South Wales Government agencies). Other work has identified broader implications of the recent Australian trends in pasture improvement activity which include export market erosion and the general degradation of Australia's pastoral resources (Menz 1984).

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[3] Previous reference has been made to the sometimes synonymous regard of fertilizer usage and pasture improvement and hence, the non-evidence of this variable in the estimated functions is a reflection of this close relationship. In this study the derived partial correlation coefficients were relatively low and hence a separate influence of fertilizer usage was anticipated.

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Appendix 1: Variable Definitions

Dependent variable (general)

SGC Area of sown grasses and clovers for each region; '000 hectares (31st March) (prefix indicates sub-region, *e.g.*, G = Gunning for GSGC).

Independent variables reported in final estimates

PWL Average price realized for greasy wool at Australian auctions; cents/kg (July–June) (suffix 1 denotes one period lag).

PBF Average auction price for beef at Sydney livestock markets; cents/kg (295–318 kg first and second export quality, July–June) (suffix 1 denotes one period lag).

PLB Average auction price for lamb at Sydney livestock markets; cents/kg (13–16 kg first and second export quality, July–June) (suffix 1 denotes one period lag).

INC Index of farm prices for wool, beef and lamb; base 1980–81 = 100.

CSTS Index of prices paid by farmers for equipment and supplies (excluding fertilizer); base 1980–81 = 100.

PFZ Price of single superphosphate ex-works, Port Kembla $/tonne (suffix 1 denotes one period lag).

SF Annual applications of superphosphate in each area; tonnes (31st March) (prefix indicates sub-region).

SEAS Rainfall recordings from representative stations in each area; adjusted by index (prefix indicates sub-region).

T Time trend; 1 in 1950, 2 in 1951, *etc.*

DUM 2 Dummy variable for major herbicides; 1 = available; 0 = not available.

DUM 3 Dummy variable for major taxation and fertilizer concessions; 1 = in operation; 0 = not in operation.

LDV Lagged dependent variable for each area.

LTVA CSTS * T.

LTVC PBF * T.

LTVD PLB * T.

Dependent variable excluded after testing

SGCA Proportion of sown grasses and clovers in the available grazing area for each region; % (31st March).

Independent variables excluded after testing

SF1 Annual application of superphosphate in each area lagged one period; tonnes.

INCA Index of farm prices for wool, beef and lamb divided by index of prices paid by farmers for equipment and supplies; base 1980–81 = 100.

EPWL Expected price for greasy wool at Australian auctions; cents/kg.

EPBF Expected auction price for beef at Sydney livestock markets; cents/kg.

EPLB Expected auction price for lamb at Sydney livestock markets; cents/kg.

DUM1 Release of major technology relative to pasture establishment; 1 = release of technology; 0 = no technology released.