ELSEVIER

Agricultural Economics 18 (1998) 63–74

AGRICULTURAL ECONOMICS

Investigating improved pasture productivity change on the New South Wales tablelands

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Accepted 15 July 1997

Abstract

The productivity of improved pastures in Australia's southeastern grazing regions is now believed to be in a state of long-term decline. As yet, there is little economic evidence to support this perception. The analysis reported in this paper seeks to examine improved pasture productivity change from an economic standpoint in a major Australian grazing area. The analysis rests on the central proposition that the productivity of the livestock enterprises is a direct reflection of pasture productivity. Using both index number and econometric methods, the results indicate that while the annual growth in livestock and hence, improved pasture productivity has been positive over the period, there has been a significant decline in legume pasture productivity. Because these pastures comprise the bulk of improved pastures, the livestock productivity of all improved pastures has declined in recent years. In contrast, the growth in livestock productivity from the perennial grass pastures continues to be high. The main reasons for legume pasture livestock productivity decline appear to be various important biological problems and the long-term decline in the farmers' terms-of-trade. Published by Elsevier Science B.V.

Keywords: Improved pasture; New South Wales; Livestock

1. Introduction

Although improved pastures comprise only 5% of Australia's total farm area, they support more than half the livestock populations (BAE, 1983). It has also been estimated that fertilised improved pastures in Australia carry 180 million more dry sheep equivalents (dse's) than unimproved pastures (Waring and Morris, 1974). Australia's improved pasture areas increased rapidly from the early 1950s to reach 29 million ha by 1971, 80% of which were in the temperate southeastern areas. On the basis of these improved pasture area and livestock population expansions, pasture improvement was regarded as being the major development in Australia's agricultural technology (Menz, 1984). Pasture improvement was also considered to be the principal source of productivity growth in the rural sector over the 1950s and 1960s (Powell, 1977). Archer et al. (1993) considered pastures to be Australia's most valuable natural resource in supplying 60% of the value of national rural output.

There is a continuing perception that the productivity of improved pastures in Australia's southeastern regions is in a state of long-term decline. In the early 1980s, Carter's (1987) views that improved pasture quality had declined because of overgrazing, and input restrictions were supported by other statements about declining pasture productivity and the concern that this was causing (AMLC, 1986). Menz (1984) referred to the growing trend in improved

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0169-5150/98/$17.00 Published by Elsevier Science B.V.
PII S0169-5150(97)00032-7

pasture degradation and the implications that this would have for Australia's livestock production and exports as well as for soil and land management. Most recently, Archer et al. (1993) concluded that while the direct evidence of improved pasture decline was mainly anecdotal from the observations by producers and pasture scientists, the few measurements available indicate that the productivity of all types of pastures had declined over the last 20 years. Reduced input use in pasture establishment and maintenance, weed infestations, soil acidity and salinity were considered to be the main contributing factors. They concluded that the problems of reduced improved pasture productivity threatened to become long-term under the economic conditions facing livestock producers.

In a biological sense, pasture productivity relates to the quantity and quality of feed made available to animals per unit area. Because the nutritional qualities of pastures vary widely, one pasture is considered to be more productive than another if its dry matter production per ha enables higher livestock production over time. It is on these feed availability and livestock production considerations that much of the concern about pasture productivity decline appears to be centred. As yet, there is little supporting evidence for these concerns on a broad area basis, except for farm census data which reveal declining improved pasture areas and livestock numbers. For example, Wheeler (1987) reported that the carrying capacity of the New South Wales non-crop areas had halved between 1970 and 1984. However, these trends are not analogous to declining pasture productivity because of the substantial differences in the carrying capacities and longevities of the dominant legumes and the perennial grasses components of the recorded improved pasture area. This means that an absolute area decline in improved perennial grass pastures would have greater productivity implications because of these pastures' superiority relative to legumes in a grazing system.

The New South Wales central and southern tablelands is an important grazing area in which the concerns about pasture productivity decline continue to be raised. Improved pastures comprise about 40% of total rural holdings with a wide range between individual shires. Livestock products contribute three-quarters of the region's annual gross value of farm production and a significant proportion of the state's livestock production. In Australia, livestock productivity and net grazing incomes have been shown to be more responsive to changes in pasture availability and quality than any other factor (Love et al., 1982). Any long-term change in improved pasture productivity would thus have major economic implications for the region and also to the nation (Menz, 1984). The purpose of this paper is to apply the methods of productivity measurement to examine the extent of change in the productivity of the main categories of improved pastures in this region over a 37-year period.

2. Methods and data

In economic terms, productivity refers to the relationship between outputs and inputs in which unit changes in output are related to unit changes in specific or groups of inputs. The plausible assessment of productivity change depends on being able to measure outputs and inputs in a logical and consistent manner over time (Antle and Capalbo, 1988). In this improved pasture context, the central proposition is that changes in improved pasture productivity are equivalent to the changes in livestock output, which are not explained by changes in the measured inputs into the pasture base. The validity of this proposition depends on the acceptance that the pasture is the major conventional input in the livestock production process. Previous analyses have identified improved pastures as being the major influence on livestock productivity (e.g., Easter, 1977;Love et al., 1982), and it is reasonable to assume that the effects of other purchased inputs, management and seasonal conditions are mainly reflected in pasture availability and quality. Similarly, a major part of the costs of livestock output are captured in the costs of providing the pasture.

This analysis proceeds on this proposition that changes in the productivity of improved pastures over time can be logically measured in terms of the changes in the levels and costs of the livestock output from these pastures. In measuring these changes, a distinction is made between the areas of improved perennial grasses and legumes within the total improved pasture area, giving the three pasture types of total improved pastures, improved perennial grasses and improved legumes.

2.1. Methods

Both index number and econometric methods have been used in the measurement and explanation of productivity change. Index numbers enable productivity change to be measured in terms of either partial productivity to specific inputs or total productivity to all inputs. Because of problems in interpreting partial productivity measures, the measurement of total factor productivity (TFP) has been more widely attempted in productivity analysis. TFP can be defined as the ratio of an index of aggregate output to an index of aggregate input for a given technology. The preference for TFP measurement arises from the practical difficulties in identifying the output contributions of separate inputs (Christensen, 1975). For multiple input production systems, TFP provides a single-series measure of the rate of productivity growth (Thirtle and Bottomley, 1992). Where the production process benefits from technological advance over time, there is a residual output which is not explained by input growth. This residual is the fundamental concept in the measurement and explanation of productivity growth.

The measurement of TFP necessitates the use of aggregate indexes of outputs and inputs which indicate the relative rates of change in the input-output series over time, and which are consistent and economically meaningful (Alston et al., 1995). Such indexes are often constructed using the Divisia approximation procedure. This indexing method provides a consistent means of aggregating multiple outputs or inputs into a single series which is based on a weighted average of the rates of change in the components continuously over time (Jorgenson and Griliches, 1971). Other types of indexes such as the Tornqvist–Theil index can be shown to be discrete approximations of the continuous Divisia index, but these differ in terms of the aggregating procedure adopted and the restrictions associated with their assumptions.

One problem with the TFP-index number approach to productivity measurement is the restrictions that it imposes on the production process. Thirtle and Bottomley (1992) note that any TFP index is restrictive relative to more flexible econometrically-estimated functions, and these problems have at times been promoted to favour the use of more flexible functional forms in productivity measurement. Other studies have used these methods to measure productivity change in Australian agriculture. For example, McKay et al. (1982) estimated a translog profit function to examine technical change in the wheat-sheep zone. A similar multi-output profit function approach was adopted by Fisher and Wall (1990) to determine the effects of technical change on sheep industry supply response. Most recently, Mullen and Cox (1994) developed a translog cost function to examine productivity growth in Australian broadacre agriculture, as well as the nature of the demand for inputs and the nature of technical change.

In this analysis, TFP-index number and econometric methods were used to determine the extent and rate of change in livestock productivity from improved pastures between 1951 and 1989. Divisia quantity indexes were derived for the quantities and costs of regional livestock outputs (wool, beef and lambs) from the three pasture types. Because the weighting procedure adopted for approximating the Divisia index components has been shown to affect the actual quantity change and the resulting TFP estimates (Alston et al., 1995), the indexes were derived using a combined weighting system that specified the weights to be the geometric average of the arithmetic average and the shares in the current and previous periods.

Since the TFP index measures the net change in output which is not explained by changes in conventional inputs, the estimated TFP ratios for livestock output for each pasture type were regressed on a set of non-conventional inputs. Elsewhere, non-conventional inputs such as farmer education and expenditure on research, development and extension have been used to explain changes in the TFP residual (e.g., Evenson et al., 1987; Mullen and Cox, 1994). Because these types of series were not available to this analysis, the non-conventional inputs considered were an index of annual average rainfall, ABARE's farmers' terms-of-trade series, a linear time trend and dummy variables for major changes in improved pasture technology (such as the release of subterranean clover varieties in the early 1950s, and the removal of the fertilizer bounty in 1975). The regressions were estimated using ordinary least squares regression and were corrected for first-order autocorrelation where necessary. A (Chow) regression coefficient stability test was used to investigate the extent of structural change in the estimated equations over the full sample period.

Thirtle and Bottomley (1992) considered that the main difference between the TFP index and production function methods for explaining productivity change was in the ability of the latter to incorporate the non-conventional variables directly into the functional relationship. They explained how the two methods were related and how this could be measured by the Tornqvist–Theil approximation of the Divisia index. [1] Furthermore, because of the restrictions imposed by any form of the TFP index (particularly constant returns to scale), the translog function was considered to offer flexibility and fewer restrictions in estimating input-output relationships. The translog function has appeal in this livestock production-improved pasture context because it allows the effects of important exogenous factors, such as weather which strongly influence pastures, to be directly incorporated into the function, and, after Alston et al. (1995), the translog is parsimonious in that it has the minimum number of parameters required to represent the production process without imposing the restrictions of the index number methods.

The cost function form of the translog has had greater application in productivity analysis than have profit or production translog functions. The main reason for this seems to be because in most agricultural production systems, prices are more variable than quantities, and farmers are more likely to base their input purchase decisions on price considerations. Also the cost minimisation requirement of the cost function is less restrictive than the objective of profit maximisation under the production and profit functions (Mullen, 1996, pers. comm.), and prices must thus appear on the right-hand-side of the cost function.

Following this reasoning, translog cost functions were specified to estimate the costs of livestock production from each pasture type. Each function incorporated a single aggregate livestock output (wool, beef and lambs), five variable input prices (labour, services, contracts, materials and livestock), two fixed input prices (land and plant-structures), and three exogenous shifters (time, rainfall and the farmers' -terms-of trade). The functions were estimated under the restrictions of symmetry on the cross-price and cross-output effects ($\alpha_{ij} = \alpha_{ji}$ for all $i,j = 1 \ldots n$, and $\beta_{kl} = \beta_{lk}$ for all $l,k = 1 \ldots m$), and linear homogeneity in input prices ($\alpha_{ij} = \alpha_{ji}$ for all $i,j = 1 \ldots n$, and $\beta_{kl} = \beta_{lk}$ for all $l,k = 1 \ldots m$). Table 1 contains the general specification of the translog cost function and the parameter definitions.

The main components of each cost function's validation were to establish whether that model satisfied the basic inequality conditions of the cost-minimisation requirement for the translog function. These conditions were that the marginal costs given by the cost share equations for all inputs ($\partial \ln C / \partial \ln Z_i$; $\partial \ln C / \partial \ln W_i$), and the marginal products of all inputs given by the revenue share equations ($\partial \ln C / \partial \ln \beta_i$) were all positive at the point of approximation which is where all W_i and Q_i were indexed to unity and the time trend was indexed to zero (Antle and Capalbo, 1988). Given the satisfaction of these conditions, the cost function was then differentiated with respect to time ($\partial \ln C / \partial T_1$) to determine the time trend parameters $\phi_{\dagger}$ and $\phi_{\dagger\dagger}$. Because input prices, outputs and the time trend were normalised to unity at the point of approximation, $\partial lnC / \partial T_1 = \phi_{\dagger} + \phi_{\dagger\dagger}$ (Capalbo, 1988). As this expression indicates the direction and rate of change in the cost function, following duality theory, it was considered to also be the indication of the significance and direction of livestock productivity change, and thence pasture productivity change, where this represented the change in total cost which was independent of changes in prices and quantities. All index number and econometric functions were estimated using the TSP econometric package Version 4.2B (TSP International, 1993).

[1] The links between these procedures are that the Tornqvist–Theil index is an exact approximation of the continuous Divisia index if the underlying production process can be represented by a homogeneous translog production function (Antle and Capalbo, 1988).

Table 1
Translog cost function specification

The general form of the translog cost function representing the cost of livestock production from improved pastures is given;	
$\ln C = \alpha_0 + \Sigma_i \alpha_i \ln W_i + \frac{1}{2}\Sigma_i\Sigma_j \alpha_{ij} \ln W_i \ln W_j + \Sigma_i \delta_i \ln Z_i + \frac{1}{2}\Sigma_i\Sigma_j \delta_{ij} \ln Z_i \ln Z_j + \Sigma_i \phi_i T_i + \frac{1}{2}\Sigma_i\Sigma_j \phi_{ij} T_i T_j$ $+ \Sigma_k \beta_k \ln Q_k + \frac{1}{2}\Sigma_k\Sigma_l \beta_{kl} \ln Q_k \ln Q_l + \Sigma_i\Sigma_k \rho_{ik} \ln W_i \ln Q_k + \Sigma_i\Sigma_k \theta_{ik} \ln Z_i \ln Q_k + \Sigma_i\Sigma_k X_{ik} T_i \ln Q_k + \Sigma_i\Sigma_j \tau_{ij} \ln W_i \ln Z_j$ $+ \Sigma_i\Sigma_j \eta_{ij} \ln W_i T_j + \Sigma_i\Sigma_j k_{ij} \ln Z_i T_j$	
where the model's parameters are:	
α_i	variable input prices: W_1 = labour; W_2 = services; W_3 = livestock; W_4 = contracts; W_5 = materials
α_{ij}	variable input price interactions
δ_i	fixed input prices: Z_1 = land; Z_2 = plant and structures
δ_{ij}	fixed input price interactions
ϕ_i	exogenous shifters: T_1 = time; T_2 = rainfall; T_3 = farmers' terms-of-trade
ϕ_{ij}	exogenous shifter interactions
β_k	Divisia index of aggregate livestock output (Q_1)
β_{kl}	output interactions
ρ_{ik}	variable factor price and output interactions
θ_{ik}	fixed factor price and output interactions
X_{ik}	exogenous shifter and output interactions
τ_{ij}	variable and fixed factor price interactions
η_{ij}	variable factor price and exogenous shifter interactions
k_{ij}	fixed factor price and exogenous shifter interactions

2.2. Data

The data used to measure output-input changes were extracted from published records over the period 1951 to 1992. The Australian Bureau of Statistics (ABS) records improved pasture areas, livestock numbers and production and fertilizer usage for New South Wales local government areas (LGA's) from the annual farm census. Also, the Australian Bureau of Agricultural and Resource Economics (ABARE) assembles index series for the main types of livestock production and for disaggregated input use for three production zones. However, there are no data which specifically relate to improved pasture outputs and inputs, and so these series have to be constructed. ABS data on improved pastures and livestock populations and production were used to calculate the livestock output series for the three pasture types (these calculations are detailed in the Appendix A).

The main requirement was to estimate the total dse's supported by the region's improved pastures, which were held to be the residual not carried on native pastures. Actual native pasture stocking rates have been the subject of recent debate with the current belief being that they have previously been substantially underestimated. Tucker et al. (1968) reported that native pastures on the New South Wales tablelands carried an average 1.8 dse's per ha. More recent evidence from this area found that these pastures are now carrying about four dse's per ha (Garden et al., 1993). This diversity is attributed to the continual modification of native pastures with fertilisers, legume introduction and grazing since the early 1950s (Campbell, 1994). [2] As the native pasture stocking rate was the basis for determining improved pasture stocking rates and their respective output series, this stocking rate was estimated from a relationship in which the overall stocking rate per ha was considered to be a function of the proportion of

[2] Campbell (1994) notes that the distinction between native and improved pastures is difficult in many situations. This difficulty is recognized, and native pastures are considered to be the balance of the total grazing area which is not identified as being either improved pasture or crop by the ABS.

improved pastures in the total grazing area. [3] The native pasture stocking rate was estimated to be about 3.25 dse's per ha for the region over the full data period.

Sheep and cattle numbers were converted into dse's and were then allocated between each pasture type according to their respective carrying capacities. Wool production and the numbers of lambs and calves were available from the ABS, but lamb and beef production had to be calculated because stock transfers do not realistically allow the conversion of livestock numbers to a regional meat production equivalent. This is because livestock disposal statistics do not indicate whether disposal was for slaughter or breeding. Many animals are sold for slaughter outside the region in which they were bred, while regional abattoirs similarly process stock from elsewhere (other animals which consume pastures were ignored as they are a very small proportion of total livestock numbers in the region).

Improved perennial grasses (such as phalaris, cocksfoot and ryegrass) and legumes (clovers, medics and lucerne) are the main components of the region's improved pastures but there is limited information on their relative proportions in the total improved pasture area. This distinction is important because the improved grasses have far superior long-term carrying capacities. Kemp and Dowling (1991) found that improved perennial species and legumes each comprised about 21% and 60% of all improved pastures on the central tablelands over 1988–1989, with the balance being weeds. While this estimate is most time-specific, it is an indication of the relative perennial grass-legume proportions and in the absence other longer-period estimates were held to have been constant over the data period. This allowed the area of improved pastures to be disaggregated and the livestock outputs from these to be estimated following the same procedures. It was assumed that the average perennial grass stocking rate was 10 dse's per ha over the range of tablelands environments (Vere et al., 1997). All pasture area and livestock data were calculated on a per ha basis so that changes in the levels of these variables could be realistically compared over the period. This was necessary because the modifications which have been made to the ABS criteria over the sample period for including farms in the census do not allow meaningful time comparisons to be made.

Input quantity and price series were derived from ABARE's indexes (for land, capital, plant and structures, labour, services, contracts and materials) for the high-rainfall zone's sheep industry section which was considered to adequately relate to the New South Wales tablelands. The input quantity and price series were fixed inputs (land, plant-structures and capital), variable inputs (labour, contracts, services, materials and livestock) and an aggregate of all inputs. Because these index series are assembled as an average per farm, they are assumed to represent the input prices and quantities required for wool, beef and lamb production on a per ha basis. This enables the returns and costs series to be considered on the same unit area basis as the pasture and livestock data. Data in common units is required by both the index number and cost function methods for estimating productivity change.

3. Results and discussion

The average annual values of the TFP ratios for livestock production per ha from the region's improved pastures and their percentage changes over time are reported in Table 2. For the total improved pasture area, the average TFP value over the 37-year period was 1.5 and changed positively at an average annual rate of about 2%. However, there were substantial differences in the annual changes in TFP between the two sub-samples (1952–70 and 1971–89), with the average TFP change after 1970 being about one-tenth the average annual change of the first period. Livestock productivity from the legume pastures appeared to have been very stable over time, but this result disguises a negative annual change after 1970. In contrast, the corresponding TFP ratios for the perennial grasses were much higher at 4.6 than those for the total improved and the legume

[3] The form of this function is $Y = a + c/(1+\exp(-b^*(x-m)))$, where Y is the regional stocking rate per ha, a and $a+c$ are the lower and upper asymptotes, x is the improved pasture area and m is the point of inflection with slope b. This function was estimated over three sub-sample periods (1953–1960, 1961–1978, 1979–1989) to reflect major changes in pasture technology such as the advent of aerial sowing. The native pasture stocking rate is given by the lower asymptote.

Table 2
Average annual TFP ratios and changes for per ha livestock production from improved pastures on the Central and Southern Tablelands: 1952–1989

	Pasture Type		
	Total improved pastures	Improved perennial grasses	Improved legumes
Average value of TFP ratio:			
1952 to 1989	1.47	4.57	1.29
1952 to 1970	1.38	2.61	1.31
1971 to 1989	1.56	6.54	1.28
Average annual change in TFP (%):			
1952 to 1989	1.99	6.27	1.55
1952 to 1970	5.03	9.19	4.83
1971 to 1989	0.54	3.51	−1.55
Average annual change in output (%):			
1952 to 1989	2.87	7.34	2.41
1952 to 1970	6.63	10.89	6.42
1971 to 1989	−0.69	3.78	−1.41
Average annual change in inputs (%):			
1952 to 1989	1.33	1.33	1.33
1952 to 1970	1.71	1.71	1.71
1971 to 1989	0.97	0.97	0.97

pastures, and these remained strongly positive over the full period.

Overall, these TFP estimates suggest that the unit area livestock productivity from all improved pastures has remained relatively stable over time and changed at an average rate of about 2% annually. However, the large livestock productivity gains made during the period of the recognised 'improved pasture revolution' up to the early 1970s (Duncan, 1972), have offset the declines thereafter. The estimates indicate that in later years, the TFP of all improved pastures has been less than unity and negative in the case of the legume pastures in which the biological problems previously indicated have been most pronounced. These productivity trends are also evident in the output and input series changes. Over the full period, the annual growth in livestock output per ha from the total improved pastures and legume categories was double the input use growth, while the same relativity was more than five-fold for the perennial grasses.

Output growth for the total improved and legume pastures was negative over the second sub-sample and positive at nearly 4% per annum for the perennial grass pastures. The decline in the total improved pastures over this period results from the dominance of the legumes in this category. Because the legumes are the pastures which have been most affected by the development of major agronomic problems, these pastures continued to constrain the livestock productivity of the total improved pastures per unit area. This productivity decline might be explained by the high livestock numbers of the mid-1970s relative to other periods, and the likelihood of input use deferral following the large cost increases over that time. Previous analyses have identified reduced input use as being the main determinant of change in livestock productivity during this period. For example, Easter (1977) found that apparent declines in sheep industry productivity in the early 1970s and subsequent increases were exactly offset by changes in input use. Input use grew at an annual rate of 1.3% over the full period, but the level of annual growth has almost halved over the second sub-sample.

The TFP regressions reported in Table 3 indicate that the non-conventional inputs (time, weather and technology) explained little of the annual variation in the TFP of livestock production from the region's improved pastures. Without the lagged dependent variable which indicates the maintenance of livestock productivity over the full sample, only the fertiliser bounty and the farmers' terms-of-trade had

Table 3
Regressions of TFP on non-conventional inputs: 1953–1989

Pasture type	Equation estimates[a]
(i) Including lagged dependent variable	
Improved	0.54 + 0.68 TFP(−1) + 0.07 DTECH + 0.27 BOUNTY − 0.002 TTRADE
	(0.8) (4.8) (0.6) (2.5) (−0.3)
	Adj. $R^2 = 0.82$; $h = 0.43$; Chow test F(3,27) = 3.33 *; $N = 36$
Perennial grasses	2.13 + 0.64 TFP(−1) + 0.22 DTEC + 0.86 BOUNTY − 0.02 TTRADE
	(0.9) (2.8) (0.5) (1.9) (−0.9)
	Adj. $R^2 = 0.79$; $h = 1.18$; Chow test F(3,27) = 8.74 * *; $N = 36$
Legumes	0.39 + 0.68 TFP(−1) + 0.05 DTECH + 0.24 BOUNTY − 0.002 TTRADE
	(0.6) (5.1) (0.5) (2.5) (−0.2)
	Adj. $R^2 = 0.72$; $h = 0.11$; Chow test(3,27) = 2.81; $N = 36$
(ii) Without lagged dependent variable	
Improved	2.39 + 0.08 DTECH + 0.33 BOUNTY − 0.01 TTRADE
	(2.4) (0.7) (1.8) (−1.7)
	Adj. $R^2 = 0.16$; DW = 1.71; Chow test(F3,29) = 3.00 *; $N = 37$
Perennial grasses	3.89 + 0.41 DTECH + 0.81 BOUNTY − 0.03 TTRADE
	(1.6) (1.1) (1.4) (−1.5)
	Adj. $R^2 = 0.08$; DW = 1.44; Chow test(F3,29) = 9.26 * *; $N = 37$
Legumes	2.31 + 0.06 DTECH + 0.31 BOUNTY − 0.009 TTRADE
	(3.5) (0.6) (1.9) (−1.6)
	Adj. $R^2 = 0.21$; DW = 1.81; Chow test(F3,29) = 1.00; $N = 37$

T-statistics are in (); [a]Estimated by OLS with a first-order autocorrelation correction. Variable definitions: DTECH, dummy variable for the release of major pasture research results (Campbell, 1996, pers. comm.); BOUNTY, subsidy on fertiliser purchases (1 = subsidy, 0 = no subsidy); TTRADE, farmers' terms-of-trade (ABARE, 1992).

any significance. The Chow tests confirmed the indications in Table 2 that there had been significant change in the structure of the TFP series for the perennial grasses and to a lesser extent, in total improved pastures. There had been no structural change in the TFP series for the legume pastures. Re-estimation of these equations with the incorporation of linear time varying parameters suggested that the major source of this change was the downward trend in the latter half of the terms-of-trade series.

The purpose of deriving the translog cost function estimates was to establish whether the indications of livestock productivity change from the TFP indexes and regressions were consistent when the non-conventional inputs were directly incorporated into the productivity relationship. This was determined from the sign and significance of the time trend parameters $\phi_{\dagger} + \phi_{\dagger\dagger}$ (Table 4). Each estimated function explained nearly all the variation in the costs of livestock output per ha from each of the three pasture types. Satisfaction of the cost-minimization regularity conditions of monotonicity in input prices and outputs was verified by establishing that the cost shares for each input and the marginal products were positive at the point of approximation.

The negative time trend parameters (ϕ_2 and ϕ_{22}) indicated that each cost function had shifted inwards at an average annual rate of about 3% independently of changes in the prices of inputs and outputs. This was considered to represent positive livestock or pasture productivity change on the basis that duality theory ensures that such change can be measured in terms of changes in the cost function (Antle and Capalbo, 1988). Most of the time effects were significant at the 5% level because of the large number of degrees of freedom which are generated under the translog estimation process. In each function, the time changes with respect to the inputs followed expectations and were significantly labour-saving but used fixed inputs, contracts and materials. It is noteworthy that the labour cost savings were offset by a large increase in the use of contract services. Similarly, the increased capital costs of land and plant provide an indication of the increased costs of the fixed inputs relative to the value of the livestock outputs produced from these inputs.

Table 4
Translog cost function estimates for per ha livestock production from improved pastures: time effects: 1953–1989

Parameter	Total improved pastures	Improved perennial grasses	Improved legumes
*Input price * time:*			
Labour ($\eta_1 \phi_2$)	−0.0002 (−7.5)	−0.004 (−4.7)	−0.006 (−7.6)
Livestock ($\eta_3 \phi_2$)	−0.001 (−1.2)	−0.0006 (−0.7)	−0.001 (−1.3)
Materials ($\eta_4 \phi_2$)	0.0007 (1.6)	0.001 (1.8)	0.001 (1.7)
Contracts ($\eta_5 \phi_2$)	0.004 (11.9)	0.011 (7.3)	0.004 (11.3)
Land ($\kappa_1 \phi_2$)	0.004 (3.4)	0.011 (3.6)	0.010 (2.1)
Plant and structures ($\kappa_2 \phi_2$)	0.004 (2.9)	0.004 (2.6)	0.004 (3.1)
Output * time (β_1)	0.033 (2.7)	0.131 (3.9)	0.027 (2.4)
Time effects:			
Time (ϕ_2)	−0.037 (−2.4)	−0.035 (−2.5)	−0.027 (−2.6)
Time * time (ϕ_{22})	−0.0002 (−1.6)	−0.0004 (−0.8)	−0.0002 (−1.6)
Adj. R^2	0.98	0.97	0.98

Some comment on the public policy implications of these results may be appropriate. Current Australian government policy relevant to pasture improvement continues to be through providing taxation concessions on and subsidised finance for farm development, and in the research and extension of information to producers. Because the decision to improve pastures is largely a private issue, declining pasture productivity through quality deterioration can be viewed as being a legitimate response to adverse economic pressures.

The economic case for government policy in agricultural issues such as pasture improvement mainly concerns the problems of information deficiencies and the presence of external costs. In this context, the main result of this analysis, which is relevant to the existing policy, is that pasture productivity problems have focused on the legumes, and that these have been pronounced in recent times. Here, the most appropriate government response would appear to be in continuing to provide information to enable producers to make better decisions about their pastures. This information would demonstrate the long-term benefits of sowing improved perennial grass pastures over the legumes, despite the higher establishment costs of the former.

4. Summary

This analysis has investigated whether there has been change in the productivity of improved pastures on the New South Wales tablelands and if so, what has been the significance and direction of that change. The analysis followed the proposition that in an economic sense, improved pasture productivity change per unit area over time was synonymous with change in the productivity of the livestock enterprises based on these pastures. Indication of change in livestock productivity was therefore considered to be a reflection of change in improved pasture productivity.

The TFP estimates indicated that over the whole period, there had been positive growth in unit area livestock productivity from improved pastures, and this had been most pronounced with the perennial grasses. While the results for each pasture category indicated positive annual growth in livestock TFP over the full period, the growth rates were much lower in the later years and negative in relation to legume pastures. Also, there had been important differences in the annual rates of TFP growth over time with strong increases up to 1970s and declines over the second half of the estimation period.

Overall, the growth in the TFP in the livestock production of the total improved pasture category had been modest and constrained by the long-term productivity decline in animal productivity within the dominant legume component. In contrast, the average rate of change in the TFP of livestock production from the perennial grasses was treble that of the other pastures. Given the low level of inputs into legume pastures relative to the perennial grasses, the productivity of the perennial pastures has been maintained at a much higher level than the legumes despite their greater purchased input requirements. This suggests that livestock producers have perceived greater economic benefits in maintaining perennial grass-based pastures than legumes when confronted by cost-price pressures.

Attempts to disaggregate the non-conventional determinants of the TFP series were inconsistent and only explainable when the previous year's TFP was included as an explanatory variable. However, the structural change tests indicated that there had been significant change in the TFP series over time, and this appeared to be due to the strong decline in the farmers' terms-of-trade after 1970. The translog cost function estimates were consistent between themselves and with the TFP estimates by indicating that there had been a significant decline over time in the costs of livestock production from each pasture type.

5. Unlinked References

Australian Bureau of Statistics, 1988, 1992

Acknowledgements

John Mullen, Garry Griffith and David Kemp made useful comments on an earlier draft of this paper. Remaining errors of logic and interpretation are the full responsibility of the author.

Appendix A

Derivation of major variables[a]

Variable	Definition	Units; Source
1. Predetermined		
Area of rural holdings	RHA	'000 ha; ABS[b]
Area of improved pastures	IPA	'000 ha; ABS
Area of crops	CPA	'000 ha; ABS
Natural pasture stocking rate	NPSR	dse per ha; estimated[c]
Sheep types (dse rating[d])		
Breeding ewes	BEWE (2.2)	
Non-breeding ewes	NBEWE(1.0)	'000; ABS
Wethers	WETH (1.0)	'000; ABS
Lambs	LAMB (0.8)	
Rams	RAM (1.8)	
Cattle types (dse rating)		
Breeding cows	BCOW (12.0)	
Non-breeding cows	NBCOW (10.0)	'000; ABS
Calves	CALF (7.0)	'000; ABS
Heifers	HEIF (8.0)	
Steers	STEER (8.0)	
Bulls	BULL (10.0)	
Wool production	WOOL	Kt; ABS
2. Calculated		
(i) Pasture areas		
Area of natural pastures	NPA	'000 ha; RHA-IPA-CPA
Area of improved perennial grasses	PGA	'000 ha; IPA $*$ 0.21[e]
Area of improved legumes	LGA	'000 ha; IPA-PGA
(ii) Livestock equivalents by pasture type		
Total sheep dse's	SDSE	'000; all sheep types $*$ dse rating
Total lamb dse's	LDSE	'000; LAMB $*$ 0.8

Total cattle dse's	CDSE	'000; all cattle types * dse rating
Total calf dse's	CFDSE	'000; CALF * 7.0
Total dses	TDSE	'000; SDSE + CDSE
Proportion of sheep in total dse's	SPROP	%; SDSE/TDSE
Proportion of lambs in sheep dse's	LPROP	%; LDSE/SDSE
Proportion of cattle in total dse's	CPROP	%; 1-SPROP
Proportion of calves in cattle dse's	CFPROP	%; CFDSE/CDSE
Cull cattle	CCULL	'000; (BCOW + NBCOW + HEIF) * 0.10
Cull cattle dse's	CCDSE	'000; (BCOW * 12.0 + NBCOW * 10.0 + HEIF * 8.0) * 0.10
Proportion of cull cattle in cattle dse's	CCPROP	%; CCDSE/CDSE
Dse's on natural pastures	NPDSE	'000; NPA * NPSR
Dse's on improved pastures	IPDSE	'000; TDSE-NPDSE
Dse's on perennial grasses	PGDSE	'000; PGA * 10.0[f]
Dse's on legumes	LGDSE	'000; IPDSE-PGDSE *
Sheep dse's on improved pastures	SDSEIP	'000; IPDSE * SPROP
Sheep dse's on perennial grasses	SDSEPG	'000; PGDSE * SPROP
Sheep dse's on legumos	SDSELG	'000; LGDSE * SPROP
Cattle dse's on improved pastures	CDSEIP	'000; IPDSE * CPROP
Cattle dse's on perennial grasses	CDSEPG	'000; PGDSE * CPROP
Cattle dse's on legumes	CDSELG	'000; LGDSE * CPROP
(iii) Livestock production by pasture type		
Wool production per dse	WLDSE	Kg; WOOL/SDSE
Wool production from improved pastures	WLIP	Kt; WLDSE * SDSEIP
Wool production from perennial grasses	WLPG	Kt; WLDSE * SDSEPG
Wool production from legumes	WLEG	Kt; WLIP-WLPG
Lambs on improved pastures	LBIP	'000; (LPROP * SDSEIP)/0.8
Lambs on perennial grasses	LBPG	'000; (LPROP * SDSEPG)/0.8
Lambs on legumes	LBLG	'000; (LPROP * SDSELG)/0.8
Lamb production from improved pastures	LPIP	Kt; (LBIP * 0.65[g] * 17.5[h])/1000
Lamb production from perennial grasses	LPPG	Kt; (LBPG * 0.65 * 17.5)1000
Lamb production from legumes	LPLG	Kt; (LBLG * 0.65 * 17.5)/1000
Calves on improved pastures	CFIP	'000; (CSPROP * CDSEIP)/7.0
Calves on perennial grasses	CFPG	'000; (CSPROP * CDSEPG)/7.0
Calves on legumes	CFLG	'000; (CSPROP * CDSELG)/7.0
Cull cattle on improved pastures	CCIP	'000; (CCPROP * CDSEIP)/10.0
Cull cattle on perennial grasses	CCPG	'000; (CCPROP * CDSEPG)/10.0
Cull cattle on legumes	CCLG	'000; (CCPROP * CDSELG)/10.0
Beef production from improved pastures	BPIP	Kt; ((CFIP * 0.85[i] * 200[j]) + (CCIP * 325[k]))/1000
Beef production from perennial grasses	BPPG	Kt; ((CFPG * 0.85 * 200) + (CCPG * 325))/1000
Beef production from legumes	BPLG	Kt; ((CFLG * 0.85 * 200) + (CCLG * 325))/1000

[a] All data relate to New South Wales Central and Southern tablelands LGA's; [b] Australian Bureau of Statistics; [c] logistic function estimate; [d] dse ratings derived from gross margin budget handbooks; [e] Kemp and Dowling; [f] average stocking rate for perennial grass pastures over all tablelands environments (Vere et al.); [g] proportion

of lambs sold for meat; [h] average lamb carcase weight; [i] proportion of calves sold for meat; [j] average calf carcase weight; [k] average cull cattle carcase weight.

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