TECHNOLOGICAL CHANGE IN THE ARID ZONE OF NEW SOUTH WALES

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The results described challenge the generally accepted interpretation of the factors underlying the changes in sheep numbers in the arid zone of New South Wales. The extent to which long-run changes in rainfall have been ignored is highlighted. Estimates of output per man are derived, using the C.E.S. production function, which show that there has been a small positive rate of technological change. Three-quarters of such technological advance has been due to factors which affect numbers of sheep carried, the remainder due to factors affecting wool production per sheep.

This paper examines the almost mechanistic interpretation of the changes in sheep numbers in the semi-arid and arid areas of Australia which is characteristically put forward as the basis of discussions relating to research, conservation, and tenure in these areas.[1] It has come to be a statement of fact that these areas when settled for grazing suffered serious and permanent reduction in carrying capacity from overstocking. It is further claimed that this man-made depletion is being continued, especially during periods of economic stress (as in the current period of low wool prices and drought), and that any stability in production which these areas may have appeared to have gained has been due to the ability of graziers to carry this exploitation over a larger area by means of additional watering points and fencing for the stock. It is claimed that landholders have not been able or willing to develop and use management practices which prevent long-term exploitation of the rangelands and that such management standards must be provided by research and implemented either by means of extension or legislation.

In an investigation of these claims one is interested in the relationships between the results of past research and the possibilities for future research, technological progress or otherwise in the grazing industry, the scope for and the effect of capital intensification, and the development of improved farming practices by graziers. A method of analysis which lends itself to an examination of these matters is the estimation of the rate of technological change and elasticity of factor substitution in the framework of the constant elasticity of substitution (C.E.S.) production function, as developed by Arrow *et al.* [3].

The analysis is concerned solely with the arid zone of N.S.W. Data have been collected for the Western Statistical Division. A definition of

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[1] For a recent example see Whalley [15].

the arid zone in N.S.W. as the area covered by the Western Division is more restrictive than that used by the Bureau of Agricultural Economics[2] or by Perry [10]. The eastern boundary of the Western Division lies some distance to the west of the boundaries set by the B.A.E. and Perry, which means that the incidence of cropping and beef cattle activities and improved pastures can be more easily ignored.

In 1968-69 the total area occupied for agricultural purposes in the Western Division was 76·7 million acres. The Division carried 11·7 per cent of the State's sheep and cut 13·3 per cent of the State's total wool production.

Settlement of the area began in the 1830's. The fastest rate of land occupation occurred in the 1870's and 1880's, due, according to Barnard [4], to the stimulus of higher wool prices. The peak of sheep numbers (14·1 millions) was reached in the early 1890's. Total sheep numbers fell to a low of 3·6 millions in 1902. Since that year sheep numbers have fluctuated within a range of 3·8 millions (1919-20) and 9·6 millions (1963-64). Accurate statistics for sheep numbers are not available prior to 1893. Data on wool production in the Division are not available before 1906. Wool production was 46·2 million lb. in 1906 and has since fluctuated within a range of 35·3 million lb. (1945-46) and 108·3 million lb. (1963-64). Wool production data for the four years 1926-27 to 1929-30 are not available.

The generally accepted interpretation of the events in the arid zone which underlie the above changes in sheep numbers and wool production proceeds in the following vein. The rate of stocking achieved in the early 1890's was far in excess of the natural carrying capacity with the inevitable consequences during the extended period of dry years from 1895 to 1902. These years of overstocking before and during the long drought period led to a permanent decrease in the carrying capacity of the zone because of the loss of plant species. For example, Perry writes: '. . . the grazing industries have been exploitative—they have been steadily mining the vegetation and land resources on which they depend for their future viability. This has not been documented by vegetation measurement but can be implied from areas in poor condition and from the trends in stock numbers. For all areas investigated stock numbers show a rapid rise following settlement, followed by a spectacular sudden crash (generally associated with a drought period) and then a recovery to a fairly steady level at about a third of peak figures. Relative stability is maintained only with continuing improvements, particularly extra watering points, which in effect bring more land within reach of stock.'[3]

Further to his last point, Perry says: 'Maintaining stock numbers by increasing the area of land grazed is obviously a short-term pattern of development which will soon come to a halt. Production may appear static now but in reality it is unstable with further decline inevitable unless management based on conservation principles is adopted.'[4]

It is argued that this continual decline in the productivity of the area will only be halted by somehow putting into practice improved management techniques developed by research. 'In Australia we are fortunate

[2] For example, see Waring [14].
[3] Perry [11, p. 258].
[4] Perry [10, p. 7].

that although almost all our arid and semi-arid pastures now have a lower carrying capacity than they had originally, a relatively small proportion of the area has been badly degraded. This is more likely due to the relatively short period of occupation than to conservative management practices.'[5] '. . . there is a challenge for research to develop management standards which maximise for long-term ecosystem stability rather than for short-term animal productivity.'[6]

These arguments pose a number of economic questions about the behaviour of graziers operating in the arid zone. First, the short-term exploitative behaviour attributed to them does not fit well in a situation where climatic considerations dictate that a long-term view be taken of farm income. Secondly, the arguments appear to deny any 'learning by doing' effect; or if there is any such effect that landholders are prepared to take advantage of it. If tenure or other considerations make landholders unwilling to improve their management practices, this affects the adoption of new practices generated from both internal and external forces. So, thirdly, what effects have new farming practices coming from research had on productivity? Fourthly, has there in fact been a shift towards more capital intensive production as implied by the argument relating to the increase in watering points?

Assumptions and Model

As stated previously, for statistical reasons the arid zone of N.S.W. is defined here as the Western Statistical Division. This restrictive definition, while not affecting the application of any results coming from this exercise, makes it easier to assume that woolgrowing is the only pastoral enterprise and that wool is the only product of the area.[7] To examine closely the nature of any technological change and the sources of any such change it has been assumed that total sheep numbers is a measure of output which excludes only the change in wool production per sheep. By this means, the estimates of the rate of technological change can be split into changes in wool per sheep and changes in ability to carry sheep. Of course, this assumption ignores the way in which sheep numbers measure the scope for income derived from selling sheep.

Because the size of and changes in the elasticity of substitution between capital and labour is of interest, the Cobb-Douglas specification of the input-output relationship, which assumes this elasticity to be equal to unity, will not be used. It will be assumed, following the C.E.S. specification developed by Arrow *et al.*, that production in the grazing industry of the arid zone can be characterized by the class of linear homogeneous functions written,

$$(1) \qquad Y = A_0 e^{\lambda t} [\delta L^{-\rho} + (1-\delta) K^{-\rho}]^{-\frac{1}{\rho}}.$$

[5] Perry [10, p. 11].

[6] See Preface to Slatyer and Perry [12, p. viii].

[7] According to the Bureau of Agricultural Economics, *The Australian Sheep Industry Survey 1960-61 to 1962-63*, Canberra, May 1965, for the 3-year period of the survey wool returns were approximately 80 per cent of sheep enterprise returns, which in turn were 91 per cent of average total returns per property for properties in the pastoral zone of N.S.W.

Output (Y) is a function of labour (L), capital (K) and changes in the level of productivity; where $0 < \delta < 1$ and $\rho > -1$ are constants, ρ being the substitution parameter related to the elasticity of substitution σ through the formula $\sigma = \frac{1}{1 + \rho}$.

In order to avoid the problems in non-linear estimation associated with estimation of the function in this form the side relation for output per man is derived and estimated. Under the postulates of perfect competition, the labour factor equilibrium condition derived from (1) can be written,

$$(2) \qquad ln(Y/L) = lnA^* + \sigma ln(W/P) + \lambda(1 - \sigma)t,$$

where $A^* = (1 - \sigma)\ lnA_o - \sigma ln\ \delta$, W/P is the real wage, and t is time. The rate of Hicks' neutral technological advance, λ, and the real wage coefficient or elasticity of substitution parameter, σ, are estimated from (2). With a valid model similar estimates for σ and λ should also be obtained from estimating a function for the output/capital ratio. These two means of estimation were not compared as the data for capital were by far the least satisfactory of all series available.

Rainfall variability must be considered a most important influence in the arid zone. Consequently, it was attempted to construct a fairly sensitive series for rainfall data to be included as shift variables in the estimating equation. Gibbs and Maher [7] and Maher [9] have compiled a series of maps of Australia showing, for the years 1885 to 1968, annual rainfall variability in terms of decile ranges. The maps illustrate annual rainfall in seven categories:

(i) very much above 'average' (decile range 10)
(ii) much above 'average' (decile range 9)
(iii) above 'average' (decile range 8)
(iv) 'average' (decile ranges 4-7)
(v) below 'average' (decile range 3)
(vi) much below 'average' (decile range 2)
(vii) very much below 'average' (decile range 1).

For the present purposes these have been given the values 3, 2, 1, 0, —1, —2, —3, respectively.[8] The value assigned in each year was made by appraisal of the overall situation in the Division.

The time of the year at which the various statistics have been collected varies over time for some series and also varies between series. In general, however, it was attempted to obtain the following relationship between the various series in the estimated equation (3),

$$(3) \qquad ln(Y/L) = lnA^* + \sigma ln(W/P) + \lambda(1 - \sigma)\ t + a_1 R + a_2 R_{-1} + a_3 R_{-2} + u$$

where L is the number of persons permanently employed in the pastoral industry at the time the annual agricultural statistics are collected (since 1931-32, at 31st March);[9] Y_w is the quantity of wool produced in the

[8] The values 4, 2, 1, 0, —1, —2, —4 were also tried but the R^2 was not altered.

[9] All persons permanently employed (including owners and managers) on agricultural holdings in the Western Division are available from 1892-93 to 1968-69. Persons permanently employed on pastoral holdings are available from 1892-93 to 1941-42. To use the latter series in the analysis it was augmented by subtracting

full year preceding the data collection date; Y_s is the number of sheep on rural holdings at each data collection date; W is the wage rate ruling at the time the agricultural statistics are collected;[10] P is the N.S.W. average greasy wool price for that year ending 30th June preceding the date the farm statistics are collected; R (lagged two periods) is the rainfall for that year ending 31st December which coincided most closely with the full year for which wool production was recorded; and u is the disturbance term.

Results

The equation estimated by ordinary least squares for wool production (Y_w) per man for the 58 years over the period 1906 to 1967 was,

$$(4) \quad ln(Y_w/L) = \underset{(0{\cdot}60)}{8{\cdot}38} + \underset{(0{\cdot}09)}{0{\cdot}13} ln(W/P) + \underset{(0{\cdot}002)}{0{\cdot}013}t + \underset{(0{\cdot}016)}{0{\cdot}027}R + \underset{(0{\cdot}016)}{0{\cdot}041}R_{-1} + \underset{(0{\cdot}02)}{0{\cdot}01}R_{-2}$$

(standard errors of coefficients in brackets) $R^2 = 0{\cdot}67$
Durbin-Watson statistic $(d) = 0{\cdot}69$

Given the above estimate of the elasticity of substitution, 0·13, the annual rate of technological advance is 1·49 per cent (calculated as (0·013/1-0·13)100). However, given the degree of positive serial correlation present in the disturbance term with the equation estimated in this form the estimated parameters are not necessarily fully efficient. One possible cause of serial correlation in the disturbance term is misspecification due to excluded variables. A possibility which suggested itself was that the farm labour market is not in instantaneous equilibrium. To investigate this hypothesis a distributed lag model of the Koyck-Nerlove type was estimated.[11] This is equivalent to including the lagged dependent variable as an explanatory variable. The resulting estimated equation was,

$$(5) \quad ln(Y_w/L) = \underset{(0{\cdot}99)}{2{\cdot}84} + \underset{(0{\cdot}067)}{0{\cdot}018} ln(W/P) + \underset{(0{\cdot}0018)}{0{\cdot}0042}t + \underset{(0{\cdot}012)}{0{\cdot}041}R + \underset{(0{\cdot}012)}{0{\cdot}022}R_{-1} - \underset{(0{\cdot}013)}{0{\cdot}017}R_{-2} + \underset{(0{\cdot}11)}{0{\cdot}68} ln(Y_w/L)_{-1}$$

$a_1 = 0{\cdot}128$ $\sigma = 0{\cdot}056$ $R^2 = 0{\cdot}81$
$a_2 = 0{\cdot}069$ $\lambda = 0{\cdot}0131$ $d = 2{\cdot}01$

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the number (or an estimate where not available) of agricultural holdings in the Division below 2,000 acres from the total number of persons employed. This was done on the assumption that these holdings would not be engaged in wool production and would not be employing more than one person, i.e., the operator. Casual labour was not included as this would be primarily for shearing; moreover, the numbers included in different categories are not identifiable. The labour series was not adjusted to a standard hours per week as there has been no statutory provision for hours worked in the pastoral industry until very recently.

[10] Data are available in the N.S.W. Statistical Register for the average yearly earnings for a stockman up to 1917. After that date, the minimum award wage for a stockhand was used.

[11] For a full discussion of this partial adjustment model see Wallis [13]. Other distributed lag models were also tried, without success, such as a simple moving average and the quadratic form of the Koyck-Nerlove model.

The result of this exercise was that the fit of the equation has been substantially improved. However, while the coefficient on the lagged dependent variable is highly significant, it is not possible to say whether or not the partial adjustment hypothesis of the labour market is substantiated as the estimated value for σ is near to zero. With these results, together with the fact that the Durbin-Watson statistic is now almost exactly 2·0,[12] one can claim to have corrected for the serial correlation bias[13] rather than to have substantiated the partial adjustment hypothesis.[14] Therefore, the coefficients estimated in (5) are preferred to those in (4); which means that the elasticity of substitution was approximately zero for this period while the average annual rate of technological progress was 1·31 per cent.[15] The picture emerges of the farm-firm operating along a fixed capital/labour path with current rainfall playing the major part in changes in output from year to year.

In order to investigate events as far into the past as possible, recourse was made to sheep numbers per man as a measure of production per man, since wool production data are not available prior to 1906. Also, in this way it was hoped to split the rate of technological change into two components—that due to changes in the carrying capacity, and that due to changes in wool production per sheep (the difference between the estimated rates of technological progress for wool production per man and sheep numbers per man). In order to calculate this difference, sheep numbers per man (Y_s/L) was used instead of wool production per man for the period 1906 to 1968. The resulting estimated equation with the lagged dependent variable correction for first-order serial correlation was,[16]

$$(6) \quad ln(Y_s/L) = \underset{(0{\cdot}79)}{2{\cdot}41} - \underset{(0{\cdot}057)}{0{\cdot}013}ln(W/P) + \underset{(0{\cdot}0013)}{0{\cdot}0032}t + \underset{(0{\cdot}01)}{0{\cdot}06}R - \underset{(0{\cdot}011)}{0{\cdot}001}R_{-1} - \underset{(0{\cdot}011)}{0{\cdot}033}R_{-2} + \underset{(0{\cdot}11)}{0{\cdot}68}ln(Y_s/L)_{-1}$$

$a_1 = 0{\cdot}187$ $\quad \lambda = 0{\cdot}01$ $\quad R^2 = 0{\cdot}78$

$a_3 = 0{\cdot}103$ $\quad d = 1{\cdot}8$

$h = 1{\cdot}3$

Comparing the results of the estimated equation for sheep numbers per man with that for wool production per man it can be seen that only one

[12] According to recent work by J. Durbin [6], a large-sample test of bias in the Durbin-Watson statistic when a lagged dependent variable is included is provided by the equation

$$h = a \sqrt{\frac{n}{1 - n\hat{V}(b_1)}}$$

where $\hat{V}(b_1)$ is the estimate of variance of the coefficient on the lagged dependent variable and $a = 1 - \frac{1}{2}d$; h is tested as a standard normal deviate.

[13] For the effects on estimation in ordinary least squares of autocorrelated errors and lagged dependent variables see Wallis [13, p. 774].

[14] See Griliches [8, p. 34].

[15] This is calculated as (0·0042/0·32)100 in the context of the partial adjustment hypothesis; see Wallis [13]. The rate of technological progress in equations (4) and (5) is thus the same, if σ is assumed equal to zero.

[16] The value of h is below 1·96 so the null hypothesis that the Durbin-Watson statistic was not biased could not be rejected.

quarter of the annual total rate of technological advance is accounted for by factors which change wool production per sheep, while the remainder is due to factors which change the numbers of sheep carried. Current rainfall affects sheep numbers per man more than wool production per man. The reason for this would seem to be the differential effect of rainfall on numbers through lambs, for which the wool yield is well below the average. Rainfall lagged two periods is not significant in regard to wool production per man but has a significant negative coefficient for sheep numbers per man. It was suspected that this was more likely a statistical phenomenon resulting from the complex lag structure which has been imposed rather than a real influence.[17]

Going back as far as the data on sheep numbers allow, i.e., the period 1892 to 1968, the estimated equation for sheep numbers per man is,

$$(7) \quad ln(Y_s/L) = \underset{(0\cdot61)}{2\cdot14} + \underset{(0\cdot058)}{0\cdot035} ln(W/P) + \underset{(0\cdot0008)}{0\cdot0025}t + \underset{(0\cdot010)}{0\cdot072}R + \underset{(0\cdot012)}{0\cdot0001}R_{-1} - \underset{(0\cdot012)}{0\cdot026}R_{-2} + \underset{(0\cdot08)}{0\cdot67} ln(Y_s/L)_{-1}$$

$a_1 = 0\cdot218$ $\quad \lambda = 0\cdot0076$ $\quad R^2 = 0\cdot78$

$a_2 = 0\cdot08$ $\quad d = 1\cdot76$

$h = 1\cdot53$

Comparing these results with those for the later period, equation (6), it is seen that the coefficients measuring the rate of technological change and the effects of rainfall are almost the same. In other words, the period from 1892 to 1905, during which overstocking was supposed to have caused the greatest damage to carrying capacity, has not affected the overall rate of increase in productivity from this source very much at all. If anything, output per man has become slightly less influenced by rainfall. (Any decrease in rainfall influence would be at least partly due to the reduction in stocking rates permitted under governmental lease conditions.) An even more important point revealed in the course of the study was that the rainfall data in Gibbs and Maher show that during the period 1885 to 1891 when the most exploitative grazing period is held to have taken place, the area experienced a series of rainfall levels which have not been approached since. In this seven-year period there were three years of rainfall 'very much above average' and two years of rainfall 'much above average'. The nearest any subsequent period has come to repeating this was during the years 1954 to 1956 when the area had two years of rainfall 'very much above average' and one year of rainfall 'above average'. In 1956-57 sheep numbers rose to 9·1 millions.

What would happen to sheep numbers if the rainfall conditions of the years 1885 to 1891 were repeated now, starting from 1969? Using

[17] That this was so was verified by estimating the equations in the form

$$ln(Y/L) = ln\ A^* + \sum_{i=0}^{n-1} \sigma(i) ln(W/P) + \lambda(1-\sigma)t + \sum_{i=0}^{n-1} a(i)\ R + u;$$

that is, by estimating a separate polynomial distributed lag [1] on the real wage and rainfall variables. According to this model, rainfall lagged once is most important in the period 1906-68, whereas in the longer period current rainfall is most important. All significant lag coefficients on the rainfall variable were positive.

the preferred equation for sheep numbers per man for the period 1906-69,

$$(8) \qquad ln(Y_s/L) = 2{\cdot}41 + 0{\cdot}0032t + 0{\cdot}06R - 0{\cdot}033R_{-2} + 0{\cdot}68ln(Y_s/L)_{-1}$$

it was calculated that by 1974-75 sheep numbers per man would be 3,428 (government leasing arrangements permitting); higher than at any time for which figures are available. Given the number of persons employed in 1892-93, this would mean a sheep population of 18·8 millions (in the peak year of 1892-93 the sheep population was 14·1 millions). Given the number of persons employed in 1956-57 or 1963-64, the two recent peaks in sheep numbers, the predicted population would be 14·2 millions and 13·0 millions respectively—well above the sheep numbers for those years of 9·1 millions and 9·6 millions.

These calculations, even given the limitations of this sort of exercise,[18] do serve to emphasize further the extent to which rainfall has been neglected by those drawing conclusions from the changes in sheep numbers.[19]

The evidence to this point certainly contradicts the extreme position that there has been an absolute decline in productivity due to exploitation in grazing. A less than extreme position might be taken to the effect that the rate of technological advance has been less than it should have been, due to the mismanagement of rangelands. A number of possibilities exist by which productivity gains may have been made. Productivity gains from external sources may or may not be embodied in new capital. Productivity gains are also possible from internal sources such as improvements in management or through economies of scale in production.

One of the features of this area is that there is little scope for on-farm investment. Moreover, the direct type of capital formation affecting carrying capacity, extra fencing and watering facilities, appears to embody little technological change. It is more likely that less obvious capital items such as road transports, overland vehicles and aircraft, and external capital formation such as roads could have contributed in this way. However, embodied technological progress will be ignored. Further, attempts to estimate the impact of economies of scale were unsuccessful. This leaves for consideration productivity gains flowing from:

(i) improved farm practices brought about by external research (whether having particular relevance to the area or not); and
(ii) 'Learning by doing' effects.

(i) *External Research as a Source of Productivity Gains*

For the arid zone the main productivity advances due to research are believed to have come from advances in knowledge about animal nu-

[18] Confidence limits could not be calculated due to the inclusion of the lagged dependent variable.

[19] Beadle [5] did run correlations between stocking rate and current rainfall and between stocking rate and rainfall lagged one period but found no correlation between them. He did comment on the high rainfall which Bourke received in 1891, but failed to realise the number of high rainfall years within the period 1885-1892. Instead he was transfixed by the differences in stocking numbers between 1890 and 1902, so much so that he concludes [5, p. 91]:

'The lack of a correlation is due mainly to the fact that pasture deterioration has assumed such vast proportions in many districts that stocking values, even in the best seasons, could never approach the high values of last century.'

trition, animal husbandry and control of rabbits. In particular, the improvements in knowledge which it is believed have been important at the individual property level, relate to nutrition, feeding economics and flock husbandry practices such as blowfly and internal parasite control. The watershed period for these advances has been taken to be the end of World War II. This period also marks the intensification of pasture research in Australia. However, the benefits from this direction are believed to have been negligible. Unlike research in animal nutrition and animal husbandry, pasture research is more geographically specific. There has been a continuing interest by all public research bodies in the arid zone (plant introduction, pasture management, etc.) since the possibilities of pasture improvement were realized, but there has been no concentrated effort in the arid zone until recently with the formation of the C.S.I.R.O. Rangelands Research Unit.

(ii) *The Learning by Doing Hypothesis*

As shown previously, one rationale for agricultural research in this zone is that research is needed to establish the sound rangelands management practices which landholders cannot or are unwilling to develop. This seems to ignore the implications of the learning by doing principle which Arrow [2] developed. The concept is briefly as follows. By repetition of the same act in a given environment, efficiency is increased —a process of learning. Changes in the environment stimulate new learning situations. New investment is postulated to impose changes on the system and thus present new learning situations. It has been argued, therefore, that to ignore the gains from learning by doing is to undervalue the contribution of capital.

In the arid zone, however, it can be argued that there has been no capital formation which has changed the environment in such a way as to present a new learning situation. But the landholder has been faced with a continually changing climatic environment. Whereas Arrow and others have assumed the contribution from learning by doing to be a function of cumulated output or cumulated investment, it seems reasonable to assume that in the present case it is purely a function of time. In other words, it is to be expected that landholders, when unfamiliar with the environment, would indeed be prone to miscalculate the carrying capacity of the land but that over time management would improve. The corollary of this line of reasoning is that research into rangeland management can be expected to yield little in the way of improved practices in the absence of a significant breakthrough in basic knowledge. It is felt that it is misleading to approach the problem of arid lands research in the manner in which it is apparently being done; as though it were an applied research problem.

If, in fact, learning by doing has been a source of productivity gains in the way outlined, it must be shown that the rate of technological advance was comparatively fast in the early years of settlement. It is hypothesised, therefore, that the annual rate of technological change should be expected to exhibit marked curvilinear features in the earliest period of settlement—with first an increasing phase followed by a decreasing phase.

To test the learning by doing hypothesis as formulated here and to see what effect there has been on productivity from the increased research effort since the war the period from 1892 to 1968 has been split into a number of sub-periods. In this way it was hoped to provide a picture of the changes in the rate of technological advance over time. Moreover, the linear estimates of λ for each sub-period for both wool production per man and sheep numbers per man were compared with curvilinear estimates obtained by solving for the equation

$$(9)\ ln(Y/L) = ln\,A^* + \sigma\,ln(W/P) + \lambda_1\,(1-\sigma)\,t + \lambda_2\,(1-\sigma)\,t^2 + a_1R + a_2R_{-1} + a_3R_{-2} + u$$

The preferred equations are shown in Table 1.

TABLE 1

Estimated Equations on Output Per Man for Various Sub-periods

X_i \ Y_i	(i) 1892-1930 Sheep Numbers per Man	(ii) 1906-1926 Sheep Numbers per Man	(iii) 1931-1968 Sheep Numbers per Man	(iv) 1931-1968 Wool Production per Man	(v) 1944-1968 Sheep Numbers per Man	(vi) 1944-1968 Wool Production per Man
$ln\ A^*$	8·97	9·83	8·22	10·2	4·86	5·05
	(1·08)	(1·63)	(0·91)	(1·02)	(1·25)	(1·52)
$ln\ (W/P)$	—0·19	—0·36	0·004	0·06	—0·09	—0·04
	(0·15)	(0·25)	(0·087)	(0·09)	(0·07)	(0·09)
t	—0·048	—0·022	—0·042	—0·049	0·0154	0·0162
	(0·012)	(0·037)	(0·021)	(0·024)	(0·004)	(0·005)
t^2	0·0013	0·0015	0·0006	0·0007		
	(0·0003)	(0·0016)	(0·0003)	(0·0003)		
R	0·136	0·105	0·048	0·037	0·051	0·048
	(0·021)	(0·03)	(0·013)	(0·015)	(0·012)	(0·014)
R_{-1}	0·085	0·06	0·036	0·038	0·018	0·017
	(0·021)	(0·023)	(0·013)	(0·015)	(0·015)	(0·016)
R_{-2}	0·043	0·02	0·006	0·018	—0·012	—0·003
	(0·023)	(0·03)	(0·014)	(0·016)	(0·016)	(0·018)
$ln\ (Y/L)_{-1}$					0·35	0·44
					(0·18)	(0·17)
R^2	0·71	0·75	0·50	0·53	0·80	0·79
d	1.20	1·41	0·82	0·90	1·25	1·59
h					(a)	2·03

(a) Not able to be calculated because $n\,\hat{V}(b_i) > 1$.

Given the problem of auto-correlated errors associated with these estimates (equations (v) and (vi) are not free of serial correlation bias) the picture which emerges is as follows. As suggested by the comparison of the λ estimates in equations (6) and (7) the period from 1892 to approximately 1910 was indeed a period of declining productivity. Productivity gains were realized from about 1910 onwards until the 1930's when there was another decline. The period since 1944 has seen comparatively high productivity gains of 2·45 per cent annually; 2·37 per cent being accounted for by factors which have influenced changes in sheep numbers per man. The implications of these results for an explanation of the sources of these gains or losses are interpreted as follows. The learning by doing hypothesis remains virtually untested as it can be argued that the bulk of the gains from this source could have been realized in the 20 years prior to 1892; a period when the area was fully settled for most of the time. While there has been an overall increase in productivity, it appears that there have been fluctuations in productivity, largely associated with periods of high and low rainfall. The results of fitting ten-year moving averages to the rainfall data support this assertion. If this is so, the ability of the area to recover its productivity must be recognized as another warning to take account of long-run factors in any interpretation of events in the arid zone. The comparatively high rate of productivity gain in recent years appears to lend support to a pay-off from research but it should be realized that this period is notable for the absence of very low rainfall years.

Discussion of Results

The interpretation which has been given of the historical changes in sheep numbers in the arid zone of N.S.W. as being entirely the result of the exploitative activities of landholders is clearly wrong. The exceptional rainfall during the period in which sheep numbers rose to the all-time peak in the early 1890's seems to have been neglected. It may be true that the carrying capacity of these rangelands has declined during periods of low rainfall, but it is just as likely true that the carrying capacity has recovered during periods of high rainfall. The simple predictive exercise described leads to the belief that if the climatic conditions experienced in the late 1880's were repeated now, that sheep numbers could be greater than the peak in the 1890's.

The implied criticism of property management appears to be unjustified. The results herein indicate that landholders have made use of the information which has been made available to them by research since 1943-44. If landholders are prepared to put into practice relevant information received from external sources, there is every reason to believe that they would make use of information coming from internal sources. Certainly there will be exceptions, but discussions at this level do not run in terms of exceptions.

It has been claimed that any increase or stability in productivity has been possible only because of the intensification of watering points. The evidence here implies that there has been no movement towards capital intensification as this argument would suggest. Because the elasticity of substitution is zero, this implies that any increase in capital formation would be accompanied by an increase in labour. Some evidence is available which bears this out. The Sheep Industry Survey data published by the B.A.E. show that between 1954 and 1957 investment in water supply facilities by properties in the pastoral zone of N.S.W. increased from 5·6 per cent of total capital to 8·1 per cent. In the same period, investment in non-livestock capital stock (water supply, fencing, building, and plant) almost doubled. This was by far the biggest increase in capital stock for these properties since the survey began in 1953. The increase in water supply facilities, absolutely, and as a proportion of total capital stock, was also the largest for the period 1953 to 1967. During the period 1954 to 1957 the number of persons employed by the pastoral industry in the Western Division rose by 16 per cent. These changes suggest a response to an economic stimulus not connected with 'exploitative' motives; for example, the 'income' effect of a change in relative prices.

Of course, the corollary to the landholders' inability to move to more capital-intensive production is that they are severely limited in the possibilities for coping with changes in the level of real wages. While the rate of technological advance achieved since 1943-44 has been surprisingly high, at least to the writer, it is surely not comparable with other sectors of the industry or of the economy in general; nor does it seem high enough to counter the inevitable squeeze on agriculture.

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