ESTIMATION OF STOCKING RATES BY MULTIPLE REGRESSION ANALYSIS

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In an article published in a previous issue of this *Review* Gruen demonstrated the possibility of using a multiple correlation analysis to estimate average stocking rates for different types of pasture grazed in common[1]. We have applied the same technique to data obtained from a sample of South-west Slope grazing properties in an attempt to estimate average stocking rates for natural and improved pastures. The attempt has not been notably successful. However, a discussion of the statistical findings may be of some interest insofar as it throws light on the theoretical and practical difficulties involved in using this technique.

The data on which the estimates are based (and on the adequacy of which more will be said later) were obtained by means of a field survey carried out in late 1954 and early 1955. The survey sample consisted of 150 randomly-selected grazing properties located in the shires of Gundagai, Tumut, Tumbarumba, Holbrook and Kyeamba[2] The following data were used in the correlation analysis:—

- y: the number of livestock, expressed in terms of dry sheep equivalents, on hand at shearing, 1954.[3]
- x_1: the acreage of unimproved grazing land (not forest) on the property.
- x_2: the acreage of improved pasture, sown in 1953 or in earlier years.

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[1] F. H. Gruen, "Stocking Rates in the Berriquin and Wakool Irrigation Districts", this *Review*, Vol. 21, No. 2 (June, 1953) pp. 113-140.

[2] Descriptive information concerning these properties has already been published in the *Review*. See Vol. 23, No. 2 (June, 1955), pp. 59-82 and Vol. 24, No. 2 (June, 1956) pp. 74-100.

[3] The following conversion ratios, which are intended to express the relative grazing requirements of different types of stock, were used:—

1 Merino, Polwarth or comeback wether = 1 dry sheep.
1 Merino, Polwarth or comeback ewe and lamb = 1⅓ dry sheep.
1 Corriedale, crossbred or British breed hogget, ewe or wether = 1⅓ dry sheep.
1 Corriedale, crossbred or British breed lamb = ⅔ dry sheep.
1 ram (any breed) = 2 dry sheep.
1 mature beef animal = 8 dry sheep.
1 steer or heifer = 5 dry sheep.
1 weaner calf = 3 dry sheep.
1 milking cow = 9 dry sheep.
1 hack = 8 dry sheep.

(Thus the grazing contribution made by forest land has been ignored as being insignificant, and areas newly-sown to improved pasture have been regarded as being unimproved.) The mean values, for each shire, of y, x_1 and x_2 are shown in Table I.

TABLE I

Characteristics of Survey Properties

(Average Quantities per Property)

Shire	Number of Stock Carried ($\bar{y}$)	Area of Natural Pasture ($\bar{x}_1$)	Area of Improved Pasture ($\bar{x}_2$)	Proportion of Grazing Land Pasture Improved	Overall Rate of Stocking
	Dry Sheep Equivalents	Acres	Acres	Per cent	Dry Sheep Per Acre
Tumut	2,758	1,092	384	26	1·9
Gundagai	4,734	1,709	641	27	2·0
Holbrook	2,130	864	538	38	1·5
Tumbarumba	3,402	483	754	61	2·8
Kyeamba	2,559	1,202	540	31	1·5
Tumut and Gundagai...	3,902	1,449	533	27	2·0

Regression equations of the form—

$$y = b_0 + b_1x_1 + b_2x_2$$

were fitted separately to the data obtained from each shire. This formulation assumes that there is a linear relationship between area of pasture and stock numbers: that 5,000 acres of pasture will usually be stocked with ten times as many sheep as 500 acres. However, it is often observed that larger properties tend to carry fewer stock per acre than the smaller properties. This may be because the larger properties tend to be found on the poorer land and/or because graziers with smaller holdings have a greater incentive to use their land more intensively. Thus it might be expected that the relationship between stock numbers and farm size is of a curvilinear nature, with stock numbers increasing at a diminishing rate as farm size increases. A straight line fitted to a set of observations which is best described by means of a curve, will be to a greater or less extent misleading but may be an acceptable approximation if the degree of curvature is not great. Such a line will not pass through the origin, but will intersect the vertical axis at some positive value of y (stock numbers). Also, its slope will best approximate to the slope of the true curve over the middle range of observations.

The regression and correlation coefficients obtained for each shire are listed in Table II. The correlation coefficients obtained for Tumut, Gundagai and Holbrook shires indicate that the fitted regression plane fits the observations quite well—that, in fact, 92, 91 and 86 per cent of the variation in stock numbers in each shire, respectively, can be explained by variations in the acreage of natural and improved pastures available. The values of b_0 (which indicates that point where the regression plane intersects the y axis) are positive—as would be expected on the assumption that the larger properties tend to stock less heavily than the smaller—but the standard errors associated with their estimation are such that it cannot be asserted that they differ significantly from zero.[4]

TABLE II

Regression and Correlation Coefficients for each Shire.

Shire	n*	b_0	b_1	b_2	$\bar{R}^2$†
Tumut ...	24	316·9 ± 205·4‡	1·19 ± 0·12	2·97 ± 0·40	·915
Gundagai ...	33	472·7 ± 387·7	1·21 ± 0·15	3·42 ± 0·29	·909
Holbrook ...	36	354·6 ± 177·6	0·75 ± 0·16	2·09 ± 0·20	·856
Tumbarumba	25	1,028 ± 358·6	1·37 ± 0·32	2·27 ± 0·38	·771
Kyeamba ...	25	—1,424 ± 964·7	1·54 ± 0·30	3·95 ± 1·30	·505
Tumut and Gundagai ...	57	327·7 ± 233·6	1·21 ± 0·12	3·42 ± 0·22	·914

* n = Number of properties.

† $\bar{R}^2$ = Square of the multiple correlation coefficient adjusted according to the size of the sample.

‡ Errors quoted are standard errors of regression coefficients.

Although the degree of correlation between stock numbers and pasture acreages is reasonably good in Tumbarumba shire, the high value of b_0 suggests that the stocking rates on large and small properties differ markedly, so that it would be misleading to quote average stocking rates for all farms. Accordingly, the analysis has been rejected as unsatisfactory. The results shown for Kyeamba shire are also unsatisfactory both on account of the low coefficient of correlation obtained, and the anomalous negative b_0 term.

Since the regression coefficients for Tumut Shire did not differ significantly from those obtained for Gundagai Shire, both sets of data were combined, and a regression plane fitted to the pooled data. The coefficients obtained are very similar to those resulting from the earlier analyses, but their standard errors are smaller. (See Table I.)

The high degree of correlation obtained from Tumut, Gundagai and Holbrook shires, together with the fact that the values of b_0 are not unduly large, suggests that the assumption of linear relationships is not likely to be grossly misleading, and that the regression coefficients b_1 and b_2 may be interpreted, with fair accuracy, as average stocking rates. Furthermore, these apparent rates—1.2 and 3.4 dry sheep equivalents per acre of natural and improved pasture respectively, for Tumut

[4] In this article, all assertions regarding significant differences are based upon five per cent level tests.

and Gundagai shires, and 0.75 and 2.1 dry sheep for Holbrook shire—do not conflict with the opinions of agriculturalists acquainted with the grazing industry in these shires. Thus the results appear to be both statistically acceptable and reasonable from a common-sense point of view. However, further analysis of the data has shown that the statistical evidence is not so straightforward as the previous analyses have suggested.

TABLE III.

Characteristics of All, Large, and Small Properties

(Average Quantities per Property)

Shire and Type of Farm	Number of Stock Carried ($\bar{y}$)	Area of Natural Pasture ($\bar{x}_1$)	Area of Improved Pasture ($\bar{x}_2$)	Proportion of Grazing Land Pasture Improved	Overall Rate of Stocking
	Dry Sheep Equivalents	Acres	Acres	Per cent	Dry Sheep Per Acre
Tumut-Gundagai—					
All Farms	3,902	1,449	533	27	2·0
Large Farms ...	7,504	2,831	1,065	27	1·9
Small Farms ...	1,956	702	245	26	2·1
Holbrook—					
All Farms	2,130	864	538	38	1·5
Large Farms ...	3,353	1,473	910	38	1·4
Small Farms ...	1,591	596	374	39	1·6

In view of the suggestion that average stocking rates per acre may be related to farm size, it was decided to subject the large and the small farms to separate analyses. In the pooled Tumut-Gundagai sample there were 20 farms greater than 2,000 acres and 37 farms of 2,000 acres or less. The Holbrook sample contained 11 properties greater than 1,500 acres and 25 of lesser area. The mean values of the data relating to these four groups of farms are given in Table III and the regression and correlation coefficients obtained are set out in Table IV.

In each district, large farms showed almost as high a degree of correlation between stock numbers and pasture areas as was found in the sample as a whole, despite the fact that the number of observations were substantially fewer. Also, the regression coefficients for the large farms did not differ substantially nor significantly from those obtained for all farms. On the other hand, in both groups of small farms, only a tenuous relationship between area and stock numbers was evident; in each case little more than 40 per cent of the variation in the latter was explicable in terms of variations in the former.[5] And as would be expected, the regression coefficients for the small farms showed some wide differences from those obtained using the data from the whole sample.[6]

TABLE IV

Regression and Correlation Coefficients for All, Large and Small Farms

Shire and Type of Farm	n	b_0	b_1	b_2	$\overline{R}^2$
Tumut-Gundagai:					
All Farms ...	57	327·7 ± 233·6	1·21 ± 0·12	3·42 ± 0·22	·914
Large Farms	20	515·2 ± 777·1	1·13 ± 0·20	3·56 ± 0·39	·886
Small Farms...	37	917·7 ± 211·6	1·01 ± 0·20	1·35 ± 0·34	·422
Holbrook:					
All Farms ...	36	354·6 ± 177·6	0·75 ± 0·16	2·09 ± 0·20	·856
Large Farms	11	233·2 ± 595·8	0·90 ± 0·34	1·98 ± 0·37	·815
Small Farms...	25	437·9 ± 412·5	0·54 ± 0·42	2·22 ± 0·52	·426

These findings lead us to conclude that the analyses made using the whole sample for each shire are dominated by the large farms. This is easily understood in terms of a three-dimensional scatter diagram: the small farms are represented by a fairly amorphous group of co-ordinates clustered relatively close to the origin, while the co-ordinates representing the large farms tend to fall about a plane extending far from the origin in each dimension. Quite drastic changes in the data relating to the small farms would have relatively little effect on a regression plane fitted to the large farm data.

The poor correlations found in some shires and for small farms are partly the result of deficiencies in the available data. These deficiencies arise from the fact that the survey sample and questionnaire were not specifically designed for the purpose of estimating stocking rates, and become apparent when the data are compared with those used by Gruen in his study of the Berriquin and Wakool Irrigation Districts. Gruen's farms were selected on the basis of soil type, whereas ours were chosen at random without reference to this factor. His data took account of

[5] Thus nothing conclusive emerges from the regression analyses regarding differences in stocking rates as between large and small properties. However, it is evident from Table III that the larger farms *do* tend to adopt lower stocking rates per acre than the small farms. In each area, both the small and the large properties have been pasture improved, on the average, to practically the same degree (26 and 27 per cent of improved pasture, respectively, in Tumut-Gundagai, and 39 and 38 per cent respectively, in Holbrook) so that direct comparisons of the overall stocking rates may be made. In Tumut-Gundagai, the average overall rate of stocking on large farms is approximately 10 per cent lower than the rate on small farms, while in Holbrook, the large farms carry on the average 12.5 per cent fewer stock per acre than the small farms.

[6] Note particularly the differing values of b_2 in Tumut-Gundagai.

seasonal variations in stock numbers but ours did not. Furthermore, the distinction between irrigated and dry-land pasture in the Berriquin-Wakool area is more clear cut than the distinction between improved and natural pasture in the South-West Slope: the differences in carrying capacities are greater, and variations in the quality of irrigated pasture are likely to be less.[7]

However, even if "perfect" data had been available, far from perfect correlations would have been obtained. Stocking rates and carrying capacities of farms reflect the influence of many factors in addition to area and type of pasture. The degree of subdivision, the availability of water, of stock handling facilities and of conserved fodder, the amount and skill of labour employed and the managerial competence of the grazier, all contribute substantially to the stock carrying capacity of a property. In view of the wide variation from farm to farm in these factors, and of the crudeness of the available data, it is not surprising that on the small farms little correlation was found between stock carried and pasture areas.[8] Among the large farms, however, the size range was sufficiently wide for differences in area to overshadow differences in the other factors affecting rate of stocking.

Although dominated by the large properties, the analyses using data from all farms still provide the best estimates of stocking rates in the shires concerned. These estimates are attended by a fair degree of error. All that can be said with a high degree of confidence is that stocking rates lie with the ranges quoted below.[9]

Tumut and Gundagai Shires:

Natural pasture 0.97—1.45 dry sheep per acre.

Improved pasture 2.98—3.86 dry sheep per acre.

Holbrook Shire:

Natural pasture 0.43—1.07 dry sheep per acre.

Improved pasture 1.69—2.49 dry sheep per acre.

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[7] Establishment of improved pastures under irrigation tends to be an "all-or-nothing" type of proposition: the cost of irrigation provides a strong incentive to strive for a highly-improved pasture. On the South-West Slope, on the other hand, such an incentive does not exist.

[8] To the extent to which the poor correlation found among the small farms was due to factors other than the inadequacy of the data, the usefulness of the concept of inherent carrying capacity or average stocking rate may be questioned. And, from the economist's point of view, the concept can be regarded as misleading since it focuses attention on only one factor—land—of the many which contribute to farm production. However, there can be no doubt that among farmers the concept is of operative significance, i.e., farmers' stocking policies are based on notions of the carrying capacities of various types of country. For this reason, rate of stocking is likely to vary less from farm to farm than either input of productive factors or output of product. The differences between well-improved and little-improved, well-managed and poorly-managed properties are often in the care with which stock are treated—and consequently show up in such matters as lambing percentages, wool cut per head, drought losses, wool and meat quality—rather than in the number of stock carried.

[9] These ranges represent 95 per cent confidence intervals about the estimated regression coefficients.

There are some theoretical grounds for believing that these figures exaggerate the carrying capacity of improved pasture and underestimate that of natural pasture. A regression analysis would give such a result if either the better land tended to be pasture improved first, or the more competent graziers tended to sow more improved pastures than the less competent. It is impossible to say how important these two tendencies might be, but it seems likely that to some extent they would tend to nullify each other.

Despite their deficiencies the estimates given may be of some interest, on account of both the importance of pasture improvement in the area, and the difficulty of securing estimates of stocking rates by other means. Experimental evidence and case studies, although useful in showing how much it is possible to increase carrying capacity by pasture improvement, give little clue as to the average increases which have occurred. The study of time-series data is complicated by the fact that the increase in the area of improved pasture over the years has been accompanied by many other changes affecting carrying capacities.