INVENTORY ANALYSIS OF DROUGHT RESERVES FOR QUEENSLAND GRAZIERS: SOME EMPIRICAL ANALYTICS*

JOHN L. DILLON
Department of Economics, University of Adelaide

AND

ALAN G. LLOYD
Faculty of Agriculture, University of Melbourne

We must assume that the economic decisions of graziers are made on a rational basis . . . In the pastoral zone drought feeding is rare. The usual practice is to stock conservatively, to sell early if the drought is anticipated, to have access to relief country and in the last resort to let the sheep take their chance.

D. D. Shaw
A.N.U. Wool Seminar, Oct. 1959.

Graziers have four basic strategies by which they may endeavour to anticipate and combat drought. They can (1) keep fodder reserves; or they can plan disposal of their livestock through (2) sale, (3) agistment or (4) death. As well, there is an infinity of possible mixtures of these basic strategies. The grazier's drought problem is to choose between these alternatives. This choice, if he is financially inclined, probably depends on his preferences between alternative gambles and on the price and technological regimes he faces. So much for the grazier's personal problem. Our problem is to provide data that will assist the grazier in his decision.

Ideally, we would like to supply enough information for each grazier to choose his most rational drought strategy. But that's impossible. There are too many differences between graziers and too many possible strategies. So we have to drop the big picture and fall back to merely providing some meaningful guides for graziers' drought planning. To this end, the derivation and implications of one such set of guides for Queensland graziers will be outlined. The major restrictions circumscribing the analysis will be noted in Section I. In Section II an outline of the inventory model used to calculate the guides will be given[1]; fol-

*Appreciation, without responsibility, is due A. A. Powell, F. G. Jarrett and D. Throsby for suggestions and criticisms, and to R. S. Northcote for computational assistance on the I.B.M. 7090.

1. The following references attest to the recent popularity of drought inventory models: Candler, W. V., " On the economics of drought reserves ", *Rev. Mark. Agric. Econ.*, 26: 215-26, 1958, and " The optimal fodder reserve—an inventory problem ", *J. Farm Econ.*, 41: 257-62, 1959; Dillon, J. L. and Mauldon, R. G., " Inventory analysis and the economics of fodder conservation ", *Econ. Record*, 35: 209-18, 1959; Mauldon, R. G. and Dillon, J. L., " Droughts, fodder reserves and stocking rates ", *Aust. J. Agric. Econ.*, 3: 35-47, 1959; and Waring, E. J., " Drought strategies and resource valuation in pastoral areas ", *Rev. Mark. Agric. Econ.*, 28: 167-77, 1960. Also relevant is: Lloyd, A. G., " Fodder conservation in the Southern Tablelands wool industry ", *Rev. Mark. Agric. Econ.*, 27: 5-50, 1959. Compared to the Dillon-Mauldon article, which related to a single Queensland region, the present analysis is based on a more comprehensive model and relates to all of pastoral Queensland.

lowed by presentation and discussion in Section III of some of the guides derived for the 42 climatic regions of Queensland's pastoral area.[2]

I

Since graziers differ in their approach to drought, it is impossible to provide full information for drought planning on an individual basis. The decision problem must be restricted somehow to make analysis feasible. The approach taken here is to: (a) confine the time of the decision to a particular set of drought circumstances; (b) assume a particular mode of planning over time; (c) restrict the array of possible strategies; and (d) assume a particular probability framework for the evaluation of alternative strategies.

Time of Planning

The simplest partitioning of the decision problem on the basis of the time of the decision is that between decisions made under non-drought conditions and those made within a drought. Since drought conditions are atypical and may be thwarted by prior planning, pre-drought decisions have the most economic significance. Accordingly *analysis is restricted to pre-drought planning*. Analytically, this is the more difficult situation. The grazier has much more information available for within-drought planning; he knows a drought has occurred and how long it has already lasted; and he has more up-to-date price information.[3]

Mode of Planning

Given the goals and preferences of a particular grazier, there is doubtless some most appropriate mode of planning for him. But as no information is available on how graziers do plan, or would like to plan if better informed, it has been necessary to postulate a synthetic planning procedure. Best described as a " rolling planning strategy ", the postulated procedure runs as follows.

Decisions are made at the start of *each* month following a non-drought month. These decisions relate to the drought strategy to be followed so as to maximize utility over the following T months. This planning period is taken as equal to the longest period without effective rain that is expected to occur on the basis of past experience. In effect, the grazier's time horizon is limited in accord with a philosophy of " look after the short run and the long run will look after itself ".[4] The planning horizon may vary between locations, over time as experience builds up, and (ideally) between different decision making months of the year. The rolling nature of the mode of planning is obvious from the fact that

2. The full array of guides derived for the 42 climatic regions will be published elsewhere.

3. Within-drought decisions are considered in Dillon and Mauldon, *op. cit.*, p. 217, and Waring, *op. cit.*

4. Ideally, a dynamic programming model encompassing all possible concatenations of future droughts would be best—but well nigh computationally infeasible. A secondary advantage of the present approach is that it avoids the problem of droughts uncompleted at the end of the planning period, as would occur with a static type of planning period (such as, for instance, if plans were made for each year on January 1).

a perspective of a given duration is continuously maintained, decisions being made each month to cover the future T months.

Strategy Restrictions

A further restriction on the decision problem is that strategies involving sale or agistment of livestock (or their converses) or the use of drought resistant species are not considered explicitly. The grazier's pre-drought planning alternatives are confined to storing fodder or letting his livestock die. This restriction of the available strategies is not too severe. Once a drought occurs, the grazier is still free to investigate agistment or sale possibilities as part of his within-drought decision problem. None the less, pre-drought recommendations that ignore agistment and sale possibilities—*ceteris paribus*—must overestimate the most appropriate level of reserve on a per animal basis.[5]

It is easy to justify the omission of strategies specifically involving drought resistant species, even though agriculturists are prone to exalt such strategies. These wonders can be allowed for through their effect on the grazier's stock of paddock feed. This stock of indigenous feed (pasture, edible scrub, etc.) stored in situ in the paddock, together with the stock of harvested feed (home-grown or otherwise) stored for potential hand feeding, constitutes the grazier's total reserve of fodder. The two classes of reserve being substitutes, it is obvious that decisions about them should be interdependent. However, unlike the size of the harvested reserve, the stock of indigenous feed is not completely under the grazier's control; it will vary with the climatic regime he faces, as well as with his stocking rate and his use of drought resistant species.

Probability Framework

The last major simplifying restriction relates to the probability framework in which drought planning decisions are to be made. Ideally, allowance should be made for the fact that each paddock has its own climatic environment, and, in consequence, its own drought length probability framework. Such a detailed approach being infeasible, some compromise is necessary. The approach adopted has been to split pastoral Queensland into climatic regions centred on the 42 climatic stations studied by Everist and Moule.[6] Although each point in a region is assumed to have the same drought length probability framework, it is not implied that droughts occur concurrently at all points in a region.

Further compromises are needed to relate climate and drought in a workable way, *drought being defined as a period during which the supply of grazing feed is inadequate to keep the desired number of livestock alive.* Undoubtedly, the occurrence of drought is contingent upon a host of climatic factors, as well as stocking rate and the types of plant or animal species involved. However, no precise data is available on the relation between stocking rate, species and drought; and climatic data in suitable form is only available for effective rain. This rainfall data consists of waiting-time probabilities for effective rain and indicates for each region the probability of having to wait various periods before effective rain

5. Over-estimation must be expected because of the automatic expansion in reserves per animal remaining on the farm that occurs if agistment or sale is decided on.

6. Everist, S. L. and Moule, G. R., " Studies in the environment of Queensland. 2. The climatic factor in drought ", *Qld. J. Agric. Sci.*, 9: 185-299, 1952.

falls[7, 8]. Accordingly, we have derived drought length probabilities from the effective rainfall probabilities. The trick consists of using stocking rate, *measured in terms of the store of indigenous feed*, as a basis for converting waiting-time probabilities for effective rain to drought length probabilities. The advantage of this approach is that it shifts the problem of assessing drought likelihood back to the individual grazier; after all, he is best qualified to estimate what his stocking rate implies in terms of the number of dry months that can occur before hand-feeding becomes necessary. Moreover, by defining stocking rate in terms of the latent supply of grazing feed, it is possible for the grazier to allow for both prior drought history and the types of pasture and animal species involved, not to mention such strategems as scrub-cutting and the spraying of dry pasture with urea.

Assuming effective rain—if it falls—falls at the end of a month, and that a single fall is sufficient to break a drought, the relation between waiting-time probabilities for effective rain and drought length probabilities in a particular region is as follows under non-drought conditions:

$$p_i(t) = \begin{cases} \sum_{j=1}^{z-x} q_i(j) & \text{for } t = 0; \\ q_i(j = z - x + t) & \text{for } t = 1, 2, \ldots, T_i - z + x \end{cases} \tag{1}$$

where we denote by:

- i : the current decision-making calendar month, $i = 1, 2, \ldots, 12$;
- $q_i(j)$: probability at the start of the i-th month of having to wait j months for effective rain;
- T_i : length of the planning horizon in use at the start of the i-th month; defined as the smallest T which gives $\Sigma q_i(j) \geqslant .999$ for the summation over j from one to T;
- z : the sequence of " dry " months that can occur with a stocking rate of $D(z)$ before hand feeding becomes necessary;
- x : number of " dry " months preceding the i-th month, $x \geqslant 0$;
- $(z-x)$: months of paddock feed on hand at the start of the i-th month, implying a current stocking rate of $D(z - x)$;
- $p_i(t)$: probability at the start of the i-th month that t months of drought will commence with month $(i + z - x + 1)$.

7. These probabilities, based on the data for the period 1893-1950 collated by Everist and Moule (*op. cit.*, pp. 274-98), have been derived by A. M. W. Verhagen and F. Hirst, *Waiting Times for Drought Relief in Queensland*, C.S.I.R.O. Math. Stat. Tech. Paper No. 9, Melbourne, 1961. In contrast to the strictly empirical probabilities—based only on sequences of dry months preceded by a wet month—used in Mauldon and Dillon (*op. cit.*, p. 49), Verhagen and Hirst use a binomial model to generate their probabilities from all sequences of dry months, whether preceded by a dry or wet month. As they note, although this approach yields many more observations for estimational purposes, it may be criticized because it assumes independence between months and thereby tends to over-estimate the probability of short sequences without effective rain. However some analyses by A. Powell (private communication) confirm their suggestion that this defect may be balanced in the present context by the loss in statistical efficiency that occurs if allowance is made for any dependence between months.

8. The concept of effective rain underlying the probabilities is outlined in Everist and Moule, *op. cit.*, pp. 186-93. Although this particular approach to effective rain does not allow for current climatic history, it does make allowance for regional variations in plant growth requirements.

Equation 1 implies that only droughts that might start in $(z - x)$ months time are considered, and that all such droughts finish within the current planning period. In other words, *only* the next possible drought is considered, and it may vary from 0 to $(T_i - z + x)$ months in length. No allowance is made for droughts not beginning at the initial exhaustion of indigenous reserves. *Ceteris paribus*, this approach undoubtedly leads to some underestimation of the most appropriate fodder reserve. Likewise, the assumption that a single fall of effective rain suffices to end a drought probably leads to some underestimation of best fodder reserve levels. However it is most likely that these underestimation effects are more than balanced by the effect of ignoring sale and agistment possibilities.

Ideally, evaluation of alternative strategies should allow for the fact (implied by the i subscript of equation 1) that the probability framework varies with the calendar month in which plans are being made. While computationally feasible, this would lead to a monstrous set of data. Consequently, a compromise procedure has been adopted: for each region, regardless of the decision month, the probabilities used are for that month of the year which had the greatest probability of having to

TABLE I

Probability of Waiting j Months for Effective Rain in Three Type-regions of Pastoral Queensland

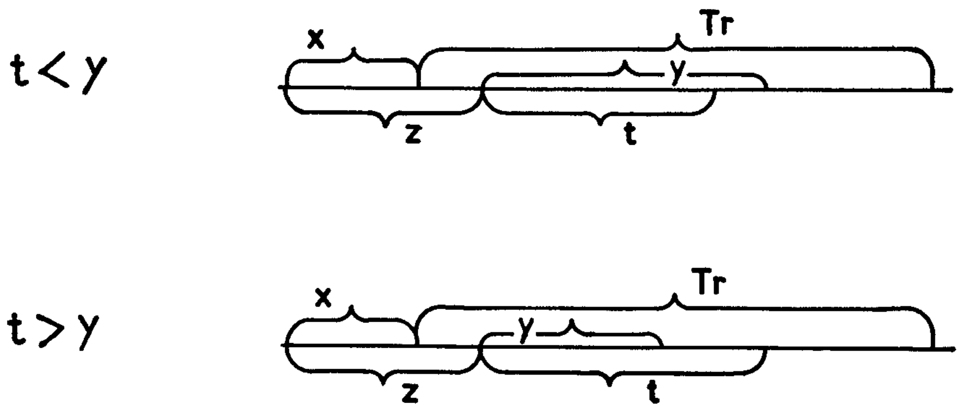
j	Region		
	Winton	Barcaldine	Roma
1	0.017	0.344	0.327
2	0.050	0.079	0.208
3	0.064	0.089	0.199
4	0.134	0.109	0.131
5	0.164	0.091	0.077
6	0.274	0.128	0.032
7	0.182	0.089	0.011
8	0.040	0.034	0.005
9	0.007	0.012	0.001
10	0.012	0.005	0.001
11	0.010	0.004	0.001
12	0.010	0.004	0.000
13	0.0006	0.0041	0.0022
14	0.0018	0.0009	0.0014
15	0.0023	0.0010	0.0013
16	0.0048	0.0013	0.0009
17	0.0059	0.0010	0.0005
18	0.0098	0.0015	
19	0.0066	0.0010	
20	0.0015	0.0004	
21	0.0000		
22	0.0004		
23	0.0004		
24	0.0003		
25	0.0000		
26	0.0001		
27	0.0001		
28	0.0002		
29	0.0002		
Total	0.9990	0.9992	0.9993

wait more than five months for effective rain.[9] Three examples of the probability distributions of waiting times for effective rain selected in this way are presented in Table I.

II

Within the framework of the compromises and restrictions noted in Section I, we now outline the model used to evaluate alternative drought strategies. By necessity, having ruled out sale and agistment possibilities, emphasis is on the possible role of fodder reserves. The dominating feature of these reserves is the inventory characteristic of the harvested fodder reserve. This reserve, unlike the store of paddock feed, will only be demanded if a drought should occur. It therefore has to be evaluated on the basis of the time-pattern of drought incidence. Assuming the past to be a reasonable guide to the future, the demand for harvested feed is specified by the probability distribution of drought length. Accordingly, a probabilistic inventory model is needed to make allowance for costs and revenues occurring either if the reserve of harvested fodder should prove too small in relation to whatever drought actually occurs, or if the reserve should prove excessive. Moreover, given the *ex ante* nature of the model, two characteristics of any possible strategy are probably of importance to a grazier in his choice between alternative strategies. These are (a) the expected net revenue of the strategy and (b) the variability that actual net revenue may exhibit around its expected value.[10] For the moment we will defer these stochastic considerations

Fig. 1



Time-scale relations between drought variables

9. Other procedures—such as choosing the month with the greatest median waiting time—would have been equally subjective. A test with three regions indicated the chosen criterion generally implied slightly larger fodder reserves than any other simple selection procedure.

10. For present purposes we accept the hypotheses (i) that graziers are risk conscious and (ii) that the variance of net revenue is the pertinent measure of risk. The latter hypothesis is more debatable than the first. Alternative risk indices might be the semi-variance, expected loss, expected absolute deviation, maximum loss, probability of loss or probability of ruin. However, with the exception of semi-variance, all these alternatives imply serious peculiarities in the decision maker's utility function. See Markowitz, H. M., *Portfolio Selection*, Wiley, New York, 1959, Chs. 9 and 13 ; also Tintner, G., " The pure theory of production under technological risk and uncertainty ", *Econometrica*, 9: 298-304, 1941. Lloyd (*op. cit.*, pp. 11-16) has suggested the probability of ruin as an index of drought risk.

and begin by specifying the model without any reference to probabilities. In such form the model is merely a mechanism for determining the net revenue that would result in the r-th region ($r = 1, 2, \ldots, 42$) over the planning period T_r if y months of harvested fodder were stored with a stocking rate of $D(z - x)$ and a drought of t months occurred. Thus, in broad form, we have for the relevant timespan:

$$R(y) = r_1 + r_2 - c_1 - c_2 - c_3 - c_4 \tag{2}$$

where:

- $R(y)$: net revenue if a supply of y months of harvested fodder is stored;
- r_1 : salvage revenue from any unused fodder reserve;
- r_2 : revenue from livestock product;
- c_1 : acquisition cost of the fodder reserve;
- c_2 : opportunity cost of keeping the fodder reserve;
- c_3 : replacement cost of livestock;
- c_4 : other costs of production.

It remains to specify the details of the model. In doing so, the following generalizations are made: only sheep are assumed to be grazed and analysis is on a sheep equivalent basis; wool is assumed to be the only product; no specific allowance is made for sheep breeding activities; harvested fodder reserves are measured in months of feed supply per sheep equivalent and, assuming efficient hand-feeding, 14 starch equivalents are taken as a month's supply of fodder; and all drought penalties are exacted via the cost of sheep death and replacement, and wool losses, rather than through fodder purchases at drought prices.

Except for five factors, the price and technological regime is assumed fixed. The five variable factors are: the prices of harvested fodder, wool and sheep; the store of harvested fodder; and the stocking rate or store of paddock feed. Throughout, any unmentioned feasibility requirements (such as adequate protein) are assumed satisfied. The various costs and revenues per sheep equivalent are postulated below. Time relationships in these costs and revenues should be clarified by reference to the time-scale examples of Figure 1.

Salvage Revenue

$$r_1 = k_1(1 - 0.01T_r)(y - t), \quad y > t, \tag{3}$$

where k_1 is the cost of a month of harvested fodder per sheep equivalent and stored fodder is assumed to deteriorate at a rate of one percent per month.

Production Revenue

$$r_2 = \begin{cases} 0.85k_2[T_r - t + (y - z + x)/2], & y < t\,; \\ 0.85k_2T_r, & y \geqslant t, \end{cases} \tag{4}$$

where k_2 is the price of wool per lb. net of freight and marketing charges, and wool production is assumed at a rate of 0.85 lb. per sheep equivalent per month. For the situation of inadequate fodder reserves, normal production revenue is discounted by the term in square brackets. This discount factor represents the simple average of two extreme possibilities: (a) that sheep are sold as soon as fodder reserves are exhausted at a price net of marketing costs equal to the value of $(z-x+y)$ months of wool production, only $(t - y)$ months of wool production being lost; and (b) that sheep die when fodder reserves are exhausted and all wool revenue over the first $(z - x + t)$ months of the planning period is lost.

Acquisition Cost

$$c_1 = k_1 y, \quad y \gtrless t, \tag{5}$$

which is simply the total outlay on harvested fodder. It is assumed that storage facilities are already available so that, apart from deterioration of the reserve, there is no significant storage cost.

Opportunity Cost

$$c_2 = 0.005 k_1 y T_r, \quad y \gtrless t, \tag{6}$$

where it is assumed that money spent on fodder could be otherwise invested at six percent per annum—a lower-limit figure taken as suitable for graziers with ample funds.

Livestock Replacement Cost

Ignoring the question of what constitutes an optimal flock policy, it is assumed the grazier follows a stable flock policy. He buys sufficient young sheep and sells sufficient old sheep at a given time each year to maintain flock numbers and average age between the desired limits for the start and end of a year. Replacement costs are measured in units of sheep months, which eliminates age of sheep as a variable. Sheep bought off-shears represent a stock of sheep months of expected life plus an expected cast-for-age value. Normal working life per sheep equivalent is assumed to be 48 months so that the expected unused working life of an average flock member is 24 months. Replacement of drought losses involves buying that number of sheep months necessary to restore the average age and size of the flock to the level which would have prevailed had no drought losses occurred.

The livestock "penalty" cost resulting from inadequate reserves involves three elements: having to buy (i) more than the "normal" number of sheep at (ii) high post-drought prices with (iii) no cast-for-age sheep to offset purchases. Sheep are assumed to die or be sold immediately upon exhaustion of the fodder reserve if it is inadequate.[11] Such sheep deaths are costed at a cast-for-age value of £1.1 per sheep equivalent plus the cost of replacing their unused months of working life at the off-shears price per sheep month prevailing immediately upon cessation of the drought.[12] This post-drought price of a sheep month is assumed to exceed the normal non-drought replacement price by £0.005 per month of drought.[13] Normal replacements to maintain the stable flock size are costed at "normal" non-drought prices.

Thus we specify

$$c_3 = \begin{cases} k_3 T_r, & y \geqslant t; \\ (24-t-z+x)(k_3+0.005t)+k_3(T_r-t-z+x)+1.1, & y < t, \end{cases} \tag{7}$$

where k_3 is the normal non-drought replacement cost of a sheep month and is taken as equal to the difference between purchase and expected cast-for-age value divided by the working life of 48 months. The formulation of production revenue and replacement cost in equations 4 and 7 respectively allows us to neglect the time of shearing and thereby avoid

11. Models endeavouring to incorporate the possibility of saving some sheep at the expense of others were used in Dillon and Mauldon, *op. cit.*, p. 215. Some illogical elements in these attempts have been noted by W. V. Candler. See also footnote 15.

12. Preliminary testing indicated the model was not very susceptible to variations in c.f.a. values between £0.8 and £1.4 per sheep equivalent.

13. Such a rise in sheep prices implies a general drought, as distinct from a local drought. Ideally, the model should incorporate this spatial dimension of drought via its effect on sheep prices.

some complications.[14] As equation 7 indicates, only normal replacements of T_r months per sheep equivalent are necessary if fodder reserves prove adequate. But with inadequate reserves, replacements consist of the months of potential working life lost due to drought-induced sheep deaths or sales, i.e. $(24-t-z+x)$ months per sheep equivalent costed at post-drought prices, plus replacements for sheep months used up between the end of the drought and the end of the planning period, i.e. $(T_r-t-z+x)$ months per sheep equivalent.

Production Cost

$$c_4 = 0.15T_r, \quad y \gtrless t, \tag{8}$$

where the monthly production cost of £0.15 per sheep equivalent is assumed to encompass all other costs of production not already specified.

Mean and Variance of Net Revenue

We may now formulate the model in probabilistic form to yield estimates of the mean and variance of net revenue. As noted previously, the probability distribution of demand for harvested fodder is taken as $p_i(t)$ for t from 0 to $(T_r - z + x)$. Accordingly, segregating the costs and revenues into those prevailing regardless of drought length, those prevailing if reserves are inadequate; and denoting the mean and variance of the distribution of net revenue for a given reserve of harvested fodder by $E(y)$ and $V(y)$ respectively; we have:

$$\begin{aligned} E(y) = & -0.15T_r - k_1y(1 + 0.005T_r) \\ & + \sum_{t=0}^{y} [k_1(1-0.01T_r)(y-t)+0.85k_2T_r-k_3T_r]p_i(t) \\ & + \sum_{t=y+1}^{T_r-z+x} [0.85k_2(2T_r+y-z+x-2t)/2-(24-t-z+x)(k_3+0.005t) \\ & \qquad -k_3(T_r-t-z+x)-1.1]p_i(t) \end{aligned} \tag{9}$$

and, remembering that the probabilities $p_i(t)$ do not sum to unity over the relevant range of t,

$$V(y) = \{\Sigma[R(y)]^2p_i(t) - 2E(y)\Sigma R(y)p_i(t)\}/\Sigma p_i(t) + [E(y)]^2 \tag{10}$$

where the summations extend over t from 0 to $(T_r - z + x)$.[15]

The net revenue characteristics given by equation 9 and 10 relate to

14. A less satisfactory approach based on time of shearing considerations was used in Mauldon and Dillon, *op. cit.*, pp. 50-2.

15. The model could be extended to encompass agistment (or sales). One approach would be along the following lines. Denote by:

- a: fraction of flock not put on agistment;
- m: months of agistment planned, $0 \leqslant m \leqslant T_r - z + x$;
- k_4: cost per sheep equivalent of a month of agistment;
- $E(y,a,m)$: mean net revenue per sheep equivalent with y, a and m; and agistment planned to commence at onset of drought.

Then we have:

$$E(y,a,m) = (1 - m/T)E(y,0,0) + (m/T)E(y/a,\ 0,0) + 0.85k_2m(1 - a) - k_4m,$$

where the first term is net revenue over the period during which no sheep are agisted; the second is net revenue from non-agisted sheep over the agistment period; and the last two terms together yield the net revenue from agisted sheep. Such extension of the analysis would increase the computational load by a factor of at least $2T$ without any allowance for alternative agistment systems such as taking agistment at times other than the onset of drought. Obviously, such extended guides would swamp most graziers' capacity for information.

the particular stocking rate in vogue during planning. For comparisons between stocking rates, these means and variances must be converted to a comparable basis. Such manipulations will not be considered here.[16]

III

Using the above model, pre-drought planning guides have been computed for each of the 42 climatic stations of pastoral Queensland that are mapped in Figure 2. Calculated on a sheep equivalent basis for the planning period of T_r months, the guides consist of arrays of seven estimates as follows:

- y^* : months of harvested fodder reserve to maximize expected net revenue;
- $E(0)$: expected net revenue with a zero reserve of harvested fodder, i.e. $y = 0$;
- $E(y^*)$: maximum expected net revenue, attained if $y = y^*$;
- $E(y^{**})$: expected net revenue with a harvested fodder reserve equal to longest drought that might occur, i.e. $y = y^{**} = (T_r - z + x)$;
- $V(0)$: variance of net revenue if $y = 0$;
- $V(y^*)$: variance of net revenue if $y = y^*$;
- $V(y^{**})$: variance of net revenue if $y = y^{**}$;

For each region, these guides have been estimated under 27 price-stocking rate regimes. These regimes were all those possible when the price of a month of harvested fodder (k_1), a lb. of wool (k_2), and a sheep month (k_3) were allowed to range over the following values:

k_1 : £0.1, 0.4, 0.7;

k_2 : £0.2, 0.35, 0.5;

k_3 : £0.03 if $k_2 = 0.2$; 0.07 if $k_2 = 0.35$; 0.11 if $k_2 = 0.5$;

with paddock reserves $(z - x)$ at levels of 0, 4 and 8 months.[17, 18, 19]

Regional Characteristics

For the 42 climatic stations Table II lists: average rainfall; mean wait for effective rain; longest expected sequence without effective rain (T_r); and the harvested fodder reserve (y^*) that maximizes expected net revenue with fodder at £0.1 per month, wool at £0.35 per lb. and a four month reserve of paddock feed. The data illustrate a typical range of y^* values across pastoral Queensland for a single price-stocking rate regime. As expected from equation 9, the ordering of y^* values follows more closely the probability characteristics of a region's rainfall rather than its absolute level of rainfall. Moreover, in every region the harvested

16. For an example of stocking rate comparisons see Mauldon and Dillon, *op. cit.*, pp. 54-6.

17. The k_1 values imply, respectively, a price of 1.71, 6.86 and 12d. per starch equivalent—corresponding respectively to the recent on-farm cost of home produced silage, purchased grain, and purchased roughage. See Skerman, P. J., " Cropping for fodder conservation and pasture production in Western Queensland " in *Report on Progressive Land Settlement in Queensland*, Govt. Printer, Brisbane, 1960.

18. Expected wool and sheep month prices have been linked on the basis that the price of a sheep normally equals about 1.5 times the value of its annual clip. Respectively, the k_3 values imply sheep equivalent prices of £2.64, 4.46 and 6.38.

19. The little evidence available suggests normal values for $(z - x)$ of around 5 to 9 months. See Waring, E. J., *op. cit.*, p. 168; and Geddes, H. J., " Combating drought ", A.N.U. Wool Seminar (Mimeo), Canberra, Oct., 1959.

TABLE II

Some Characteristics of 42 Climatic Centres in Pastoral Queensland

Centre[a]	Av. annual rainfall[b]	Mean wait for effective rain	T_r[c]	y^*[d]
	ins.	mths.	mths.	mths.
Urandangie	13.95	8.61	36	16
Boulia	11.24	8.25	36	10
Thargomindah	11.63	7.52	36	10
Windorah	12.40	7.41	36	8
Camooweal	16.02	6.44	24	5
Cloncurry	18.83	6.39	30	6
Jundah	12.83	6.26	32	8
S. Comongin	13.17	6.10	35	8
Winton	17.56	5.93	29	4
Kynuna	17.69	5.79	30	5
Richmond	19.42	5.78	21	5
Eulo	13.81	5.63	31	8
Adavale	15.15	5.05	28	7
Cunnamulla	15.07	5.02	25	8
Isisford	18.11	4.93	27	5
Hughenden	20.51	4.71	20	5
Longreach	18.73	4.63	27	6
Aramac	19.16	4.17	25	5
Barcaldine	20.47	3.75	20	5
Blackall	21.22	3.38	19	5
Alpha	20.42	3.26	18	4
Clermont	25.75	3.24	18	3
Dirranbandi	16.78	3.00	17	4
Emerald	24.88	2.92	18	5
Springsure	27.85	2.87	18	5
St. George	19.40	2.87	17	4
Bollon	16.19	2.85	17	5
Charleville	19.37	2.84	18	5
Tambo	20.83	2.82	18	4
Mitchell	22.64	2.80	17	4
Roma	22.70	2.68	17	3
Augathella	18.77	2.49	17	4
Morven	22.22	2.43	17	4
Surat	22.68	2.39	16	2
Muckadilla	19.24	2.19	17	3
Dalby	27.33	2.15	15	2
Taroom	26.71	2.06	15	3
Pittsworth	28.02	2.02	14	0
Yuleba	23.87	1.98	15	2
Goondiwindi	22.66	1.90	14	0
Miles	26.10	1.77	14	2
Warwick	29.52	1.76	14	0

(a) Ordered in terms of the mean wait for effective rain of col. 3.

(b) From Everist and Moule, *op. cit.*, p. 116. Generally based on records for the period 1894 to 1951.

(c) Longest sequence without effective rain expected to occur. Probability of a longer sequence is less than 0.001.

(d) Reserve of harvested fodder to maximize expected net revenue per sheep equivalent with fodder at £0.1/mth., wool at £0.35/lb., a four month reserve of paddock feed, and the price of a sheep month at £0.07.

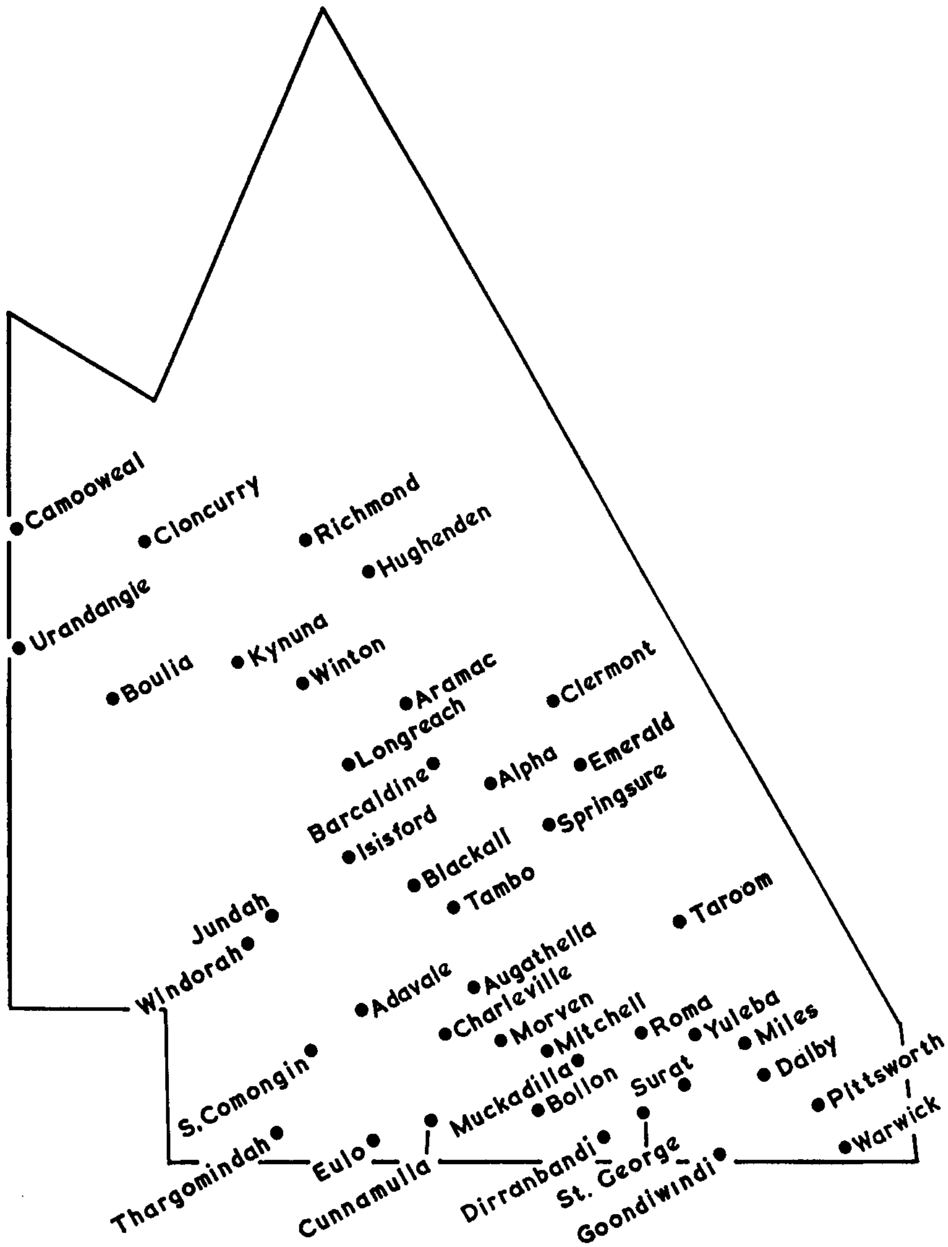


Fig. 2 Forty-two climatic centres in pastoral Queensland.

reserve to maximize expected profit is *much* less than the longest expected drought of $(T_r - 4)$ months. Still, no stress should be laid on this divergence without considering the variability of net revenue and the role of grazier's risk preferences.

The mean and standard deviation of net revenue with zero, expected profit maximizing, and maximum reserves of harvested fodder in each region are listed in Table III for the same price-stocking rate regime used in Table II.[20] To illustrate the information content of such guides, consider the case of a Urandangie grazier operating under the appropriate

20. Any attempt at inter-regional comparisons among the guides should make allowance for variations in the length of the planning period, not to mention the typical lack of homogeneity in the on-farm price of harvested fodder and in paddock reserve levels.

TABLE III

Mean and Standard Deviation of Net Revenue with Various Fodder Reserves in Pastoral Queensland[a]

Region[b]	Mean, $E(y)$, when:			Standard deviation, $[V(y)]^{\frac{1}{2}}$, when		
	$y = 0$[c]	$y = y^*$[d]	$y = y^{**}$[e]	$y = 0$	$y = y^*$	$y = y^{**}$
	£	£	£	£	£	£
Urandangie	−0.59	1.49	0.74	1.61	0.88	0.37
Boulia	−0.22	1.47	0.73	1.97	1.58	0.41
Thargomindah	0.12	1.60	0.80	2.06	1.42	0.35
Windorah	0.09	1.66	0.82	1.96	1.52	0.33
Camooweal	−1.25	1.34	0.94	1.19	0.88	0.20
Cloncurry	−0.50	1.73	0.95	1.61	0.84	0.19
Jundah	0.04	1.68	0.95	1.84	1.12	0.26
S. Comongin	0.51	1.83	0.90	2.01	1.21	0.26
Winton	−0.31	1.64	1.01	1.60	1.16	0.20
Kyuna	−0.36	1.76	0.99	1.57	0.96	0.20
Richmond	−1.01	1.19	0.89	1.63	0.68	0.26
Eulo	0.38	1.68	0.98	1.97	1.01	0.26
Adavale	0.32	1.61	1.04	1.83	0.87	0.20
Cunnamulla	0.13	1.42	1.01	1.87	0.70	0.24
Isisford	0.33	1.59	1.05	1.79	0.97	0.18
Hughenden	−0.36	1.21	0.93	1.80	0.55	0.19
Longreach	0.25	1.58	1.04	1.81	0.88	0.18
Aramac	0.39	1.54	1.05	1.76	0.77	0.19
Barcaldine	0.24	1.23	0.98	1.70	0.67	0.20
Blackall	0.38	1.20	0.97	1.62	0.58	0.19
Alpha	0.39	1.20	0.96	1.53	0.44	0.17
Clermont	0.33	1.21	0.96	1.54	0.50	0.15
Dirranbandi	0.60	1.07	0.94	1.40	0.68	0.22
Emerald	0.74	1.19	0.97	1.37	0.40	0.17
Springsure	0.76	1.20	0.97	1.35	0.36	0.16
St. George	0.70	1.12	0.94	1.31	0.56	0.21
Bollon	0.64	1.09	0.94	1.37	0.56	0.17
Charleville	0.59	1.15	0.96	1.47	0.58	0.18
Tambo	0.61	1.21	0.97	1.42	0.42	0.16
Mitchell	0.83	1.16	0.96	1.17	0.40	0.19
Roma	0.87	1.17	0.96	1.13	0.50	0.22
Augathella	0.66	1.12	0.94	1.35	0.54	0.16
Morven	0.76	1.13	0.95	1.26	0.50	0.18
Surat	0.85	1.12	0.92	1.06	0.49	0.25
Muckadilla	0.82	1.16	0.95	1.19	0.52	0.17
Dalby	1.04	1.06	0.91	2.06	0.48	0.07
Taroom	0.90	1.05	0.90	0.92	0.40	0.08
Pittsworth	1.03	1.03	0.87	0.45	0.45	0.04
Yuleba	0.90	1.07	0.90	0.89	0.37	0.05
Goondiwindi	1.04	1.04	0.87	0.41	0.41	0.04
Miles	0.98	1.00	0.87	0.61	0.41	0.06
Warwick	1.05	1.05	0.87	0.36	0.36	0.04

(a) On a sheep equivalent basis with fodder at £0.1/mth., wool at £0.35/lb., a four month reserve of paddock feed, and the price of a sheep month at £0.07.

(b) Ordered as in Table II.

(c) Zero months reserve of harvested fodder.

(d) Harvested fodder reserve to maximize expected net revenue over the planning period.

(e) Harvested fodder reserve equal to the length of the longest expected drought.

price-stocking rate regime. Assuming approximate normality in the distribution of net revenue for a given reserve of harvested fodder, row 1 of Table III implies that in about 68 percent of plays with zero, expected profit maximizing, and maximum reserves, his net revenue will lie, respectively, between £—0.59 ± 1.61, £1.49 ± 0.88, and £0.74 ± 0.37. (Corresponding reserves are 0, 16 and 32 months.) Which of these strategies is preferred will depend on the grazier's gambling preferences. In large part the remainder of this paper is concerned with such problems of choice, as exemplified by the guides for the Barcaldine region listed in Table IV. Although lack of space prevents the consideration of other type-regions, the Barcaldine results outlined below are typical of all 42 regions.

TABLE IV

Barcaldine Drought Planning Guides

(T = 20 months)

Price-stocking rate regime			Guides[a]						
Paddock reserve ($z - x$)	Fodder price (k_1)	Wool price (k_2)	y^*	$E(0)$	$E(y^*)$	$E(y^{**})$	$V(0)$	$V(y^*)$	$V(y^{**})$
mths.	£/mth.	£/lb.	mths.	£	£	£	£^{2}	£^{2}	£^{2}
0	0.1	0.2	9	−2.8	−0.8	−1.1	0.25	0.34	0.05
		0.35	9	−2.2	0.9	0.6	0.40	0.54	0.05
		0.5	9	−1.5	2.6	2.4	0.58	0.78	0.05
0	0.4	0.2	7	−2.8	−2.4	−3.8	0.25	1.59	0.80
		0.35	7	−2.2	−0.7	−2.0	0.40	2.20	0.80
		0.5	8	−1.5	1.0	−0.3	0.58	2.04	0.80
0	0.7	0.2	0	−2.8	−2.8	−6.5	0.25	0.25	2.46
		0.35	1	−2.2	−1.8	−4.8	0.40	3.61	2.46
		0.5	7	−1.5	−0.5	−3.0	0.58	4.63	2.46
	0.1	0.2	4	−1.1	−0.5	−0.8	1.43	0.35	0.04
		0.35	5	0.2	1.2	1.0	2.88	0.45	0.04
		0.5	5	1.6	3.0	2.7	4.82	0.68	0.05
	0.4	0.2	3	−1.1	−1.0	−2.5	1.43	0.88	0.40
		0.35	3	0.2	0.7	−0.7	2.88	1.40	0.41
		0.5	4	1.6	2.4	1.0	4.82	1.37	0.42
4	0.7	0.2	0	−1.1	−1.1	−4.1	1.43	1.43	1.17
		0.35	0	0.2	0.2	−2.4	2.88	2.88	1.19
		0.5	3	1.6	1.9	−0.6	4.82	2.67	1.20
8	0.1	0.2	0	−0.3	−0.3	−0.6	0.24	0.24	0.02
		0.35	1	1.4	1.5	1.2	0.47	0.35	0.02
		0.5	1	3.1	3.2	2.9	0.76	0.56	0.03
8	0.4	0.2	0	−0.3	−0.3	−1.7	0.24	0.24	0.12
		0.35	0	1.4	1.4	0.1	0.47	0.47	0.13
		0.5	0	3.1	3.1	1.8	0.76	0.76	0.14
8	0.7	0.2	0	−0.3	−0.3	−2.8	0.24	0.24	0.33
		0.35	0	1.4	1.4	−1.0	0.47	0.47	0.35
		0.5	0	3.1	3.1	0.7	0.76	0.76	0.36

(a) For explanation of the heading notation, see Table III.

Apart from expected profit following the pattern of change expected with variations in the price and stocking rate parameters, the data of Table IV exhibits some noteworthy features. Firstly, *only* with " high " wool prices and a cheap source of harvested fodder is it ever worthwhile keeping a reserve if expected profit maximization is the sole criterion and paddock feed reserves are more than about 6 or 7 months. This is exemplified by the frequency with which $y^* = 0$ when there are paddock reserves of eight months. Second, harvested reserves to maximize expected profit are fairly insensitive to variations in wool price (and sheep replacement costs) as shown by comparing the y^* values within each triplet of regimes. Hence mistakes in predicting wool price will not generally nullify an expected profit-maximizing choice of strategy. Likewise, judged on the implicit sheep replacement cost effects, reformulation of the model to encompass sheep breeding activities would have little influence on y^* values since the only significant effect of introducing ewes would be to increase replacement costs. Lastly, there are sizable shifts in the variance pattern from one price-stocking rate regime to another. Indeed, if the mean and variance of net revenue are dominant factors in strategy choice and gambling is not preferred for its own sake, then in only 2 of the 27 price-stocking rate regimes of Table IV is strategy choice independent of a grazier's gambling preferences. Obviously this result is in conflict with exhortations that imply fodder reserves are desirable regardless of a grazier's feelings about risk. It deserves some elaboration.

Role of Gambling Preferences

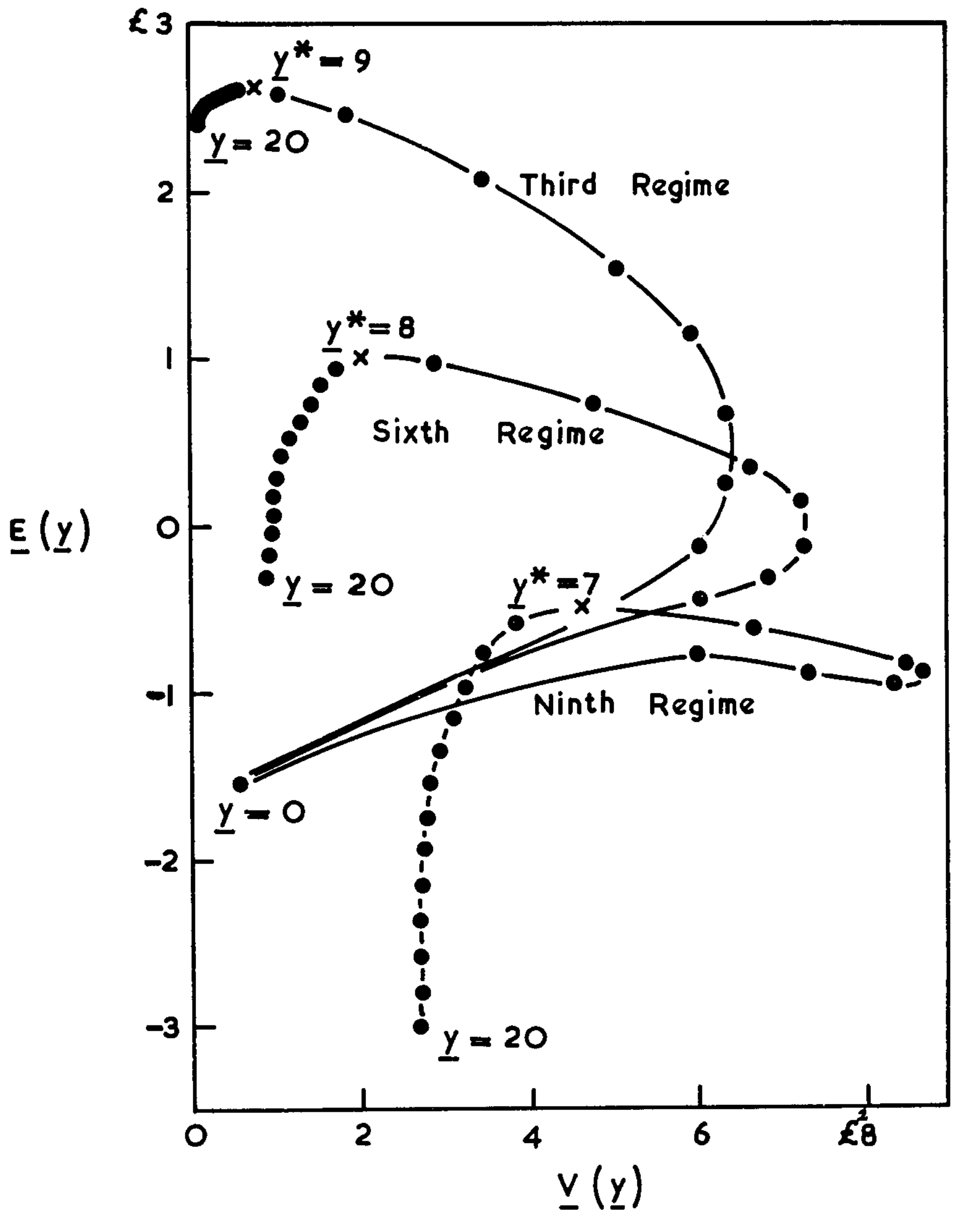
Appreciation of the role of graziers' gambling preferences may be gained from Figure 3. From top to bottom respectively, it shows the graphs of expected net revenue $[E(y)]$ versus the variance of net revenue $[V(y)]$ for the third, sixth and ninth regimes of Table IV. Each curve covers harvested fodder reserves from 0 to 20 months, the longest expected drought at Barcaldine with a zero reserve of paddock feed. The shape of the curves is largely explained by the fact that (i) as y initially rises from zero, $V(y)$ increases because of increasing possibilities of fluctuations in $R(y)$ (arising from the greater chance with low y of losing both sheep and reserves), while (ii) beyond a certain level of y, $V(y)$ decreases as fluctuations in $R(y)$ are increasingly brought under control by increases in y.

For each regime of Figure 3 the choice of a rational strategy (i.e. of a y value) depends on the shape of the grazier's (E,V) indifference system. To illustrate, consider the middle graph; it refers to the sixth regime of Table IV. Assuming gambling is not preferred *per se*, this graph implies that for all possible (E,V) indifference systems the rational choice must be $8 \leqslant y \leqslant 20$ or $y = 0$. All other feasible strategies are inefficient; they have smaller certainty equivalents regardless of the grazier's gambling preference system. Under this regime a grazier indifferent to risk should choose $y = y^* = 8$. In contrast (and paradoxically for conservationists), a grazier who completely abhorred risk should choose $y = 0$.

Similar (E,V) considerations apply for the other regimes graphed in Figure 3. The third regime (top graph) has a range of rational choice of $9 \leqslant y \leqslant 20$. All three graphs indicate that graziers who prefer to gamble for its own sake should never keep zero reserves of harvested fodder. This is invariably true for all price regimes in all regions. Conversely, it is somewhat inaccurate to talk of a reserve equal to the longest expected drought as the "no-risk reserve". Indeed, a grazier preoccupied with survival might best insure himself by keeping zero reserves and selling his sheep at the first sign of drought, thereby husbanding his reserves so as to be sure of "living to fight another day". For such a grazier the probability of ruin would most likely serve as an appropriate index of drought risk.

In so far as the graphs of Figure 3 are typical, it is evident that variance considerations are important for all 42 climatic regions. This is further evidenced in Table V which lists for the three type-regions of Winton, Barcaldine and Roma the frequency of various combinations of efficient

Fig. 3



Mean versus variance of net revenue for fodder reserves from 0 to 20 months at Barcaldine under regimes 3, 6 and 9 of Table IV.

strategies among the three strategies ($y = 0$, y^* and y^{**}) encompassed by the derived guides. The most common set of efficient strategies consists of the expected profit maximizing and maximum reserve strategies. In a few cases all three strategies are efficient while in 11 cases the efficient strategy set is limited to a single possible choice—that of a zero reserve coinciding with an expected profit maximum.

Of course, the 81 regimes summarized in Table V include many that are hardly relevant to 1962 conditions. If we omit regimes involving the highest wool price (£0.5 per lb.), the highest fodder price (equal to £1.15 per bushel of wheat) and zero paddock reserves, we are left with 8 regimes at each of the three locations. These 24 regimes are probably most relevant for current drought prolepsis by Queensland graziers. Among these 24 regimes, efficient choice lies between y^* and y^{**} in 14 cases, and between $y^* = 0$ and y^{**} in 10 cases. However, in only 8 of the 24 cases does there seem much likelihood that the maximum reserve would be preferred to the expected profit maximizing reserve.

TABLE V

Specification and Frequency of Efficient Drought Strategies at Winton, Barcaldine and Roma

Efficient strategy sets[(a), (b)]	Winton		Barcaldine		Roma	
	Freq.	Regime Nos.[(c)]	Freq.	Regime Nos.	Freq.	Regime Nos.
$y = 0, y^*$, or y^{**}	1	17	2	5, 6	2	5, 6
$y = 0$ or y^*	3	5, 6, 9	3	4, 8, 9	3	4, 8, 9
$y = 0 = y^{**}$	5	4, 7, 8, 16, 25	2	7, 25	4	7, 22, 25, 26
$y = 0 = y^*$ or y^{**}	7	19, 20, 22, 23, 24, 26, 27	8	16, 17, 19, 22, 23, 24, 26, 27	8	16, 17, 19, 20, 21, 23, 24, 27
$y = y^*$ or y^{**}	11	all others	12	all others	10	all others

(a) For explanation of the notation, see Table III.

(b) Assuming the only information available is that of the guides and the decision maker has no preference for gambling *per se*.

(c) Regime numbering corresponds to the listing of the price-stocking rate regimes in Table IV.

Conclusions

So far as can be generalized, the data of Table V indicates that rational choice across the derived guides tends to devolve to: (a) choosing between expected profit maximizing and zero reserves if the paddock feed reserve is less than four months and fodder is not very cheap; and (b) to a choice between expected profit maximizing reserves (frequently coinciding with zero reserves) and maximum reserves if paddock reserves are four months or greater. For the latter circumstances, study of the relation between the mean and variance of net revenue over the various regimes involving 4 or 8 months of paddock reserves indicates graziers not rabidly averse to income variability would generally choose the expected profit maximizing strategy. (In this regard the middle graph of Figure 3 is typical.) Moreover, with four or more months of paddock reserves, the expected profit maximizing reserve of harvested fodder is generally quite small—as evidenced by the y^* values of Tables II and IV. Thus, remembering (i) that the analysis is based on conservative probabilities, has ignored agistment and sale possibilities (both of which are strong substitutes for fodder reserves[21]) and has assumed a low (6%) opportunity cost for capital, and (ii) that available evidence (albeit scant) indicates normal non-drought paddock reserves of at least five months, *the current analysis suggests the best drought policy for most Queensland graziers would be*

21. Under certainty, fodder reserves and agistment are perfect substitutes so that under the usual price conditions in pastoral regions (see Geddes, *op. cit.*), agistment would generally be preferred to fodder reserves. However, perfect substitution does not necessarily occur under conditions of risk or uncertainty. See Dillon, J. L. and Powell, A. A., " Factor substitutability and probability distributions of factor services ", *Economic Journal,* (In Press), 1962.

to keep zero or very small reserves of harvested fodder. Conversely, anyways substantial reserves only appear appropriate for those few graziers who have a cheap source of harvested fodder, less than four months of paddock reserves (i.e. a high stocking rate or incipient drought conditions), a very strong aversion to income variability, and are located in a region with a mean waiting time for effective rain of more than five months.

It is interesting to compare the above conclusions with the available evidence on the actual drought strategies of Queensland graziers. This evidence comes from three field surveys.[22] All three indicate the holding of pre-drought reserves of harvested fodder is a rare strategy choice. Of a total of 144 survey properties, only about 12 kept such reserves. With respect to within-drought strategies, 24 percent purchased agistment, 42 percent sold sheep, 38 percent cut scrub and nine percent did nothing; only 24 percent used any harvested fodder.

While it is a happy result that the survey data is not in conflict with our conclusions, this evidence does not provide a test of the model. After all, the model is a normative one. Concurrence between its implications and the actual behaviour of graziers could arise through coincidence; or because the model does have descriptive value to the extent, say, that graziers do base their drought planning on intuitive measures corresponding to the mean and variance of net revenue. Maybe the future will see some actual testing of this and associated hypotheses—for instance, is graziers' rejection of the perennial recommendation to store fodder merely the result of an unreasoned do-nothing policy; or does it reflect rationality beyond the capacity of conservation propagandists ? Certainly the results of this study give little support to the view that graziers' investment in harvested fodder is suboptimal and that State intervention through subsidy or a national fodder reserve is therefore justified. Proponents of such schemes would seem to bear the onus of proof that there is a marked divergence between the private and social net benefit from harvested fodder reserves.

Finally, despite our general conclusion that small or zero reserves of harvested fodder should be most common, the derived guides must be judged of real use to graziers. Taken in conjunction with the grazier's own information and experience, they provide a better information base for pre-drought planning than is currently available elsewhere—so long as one accepts that the mean and variability of net revenue are important considerations in drought planning, and that the imposed compromises, restrictions and technical assumptions are not too unreal.

22. Anon., " A survey of sheep properties in the Longreach-Blackall district, Central-West Queensland" in *Regional Studies of the Australian Woolgrowing Industry*, B.A.E., Canberra, 1951, pp. 44-5; Anon., *Australian Sheep Industry Survey* 1954: *Queensland*, B.A.E., Canberra, 1956, p. 13; and Bird, A. R., " A Study of the factors responsible for fluctuations of sheep numbers in the Charleville district, 1939-49 ", *Qld. Univ. Papers*, 1: 43-85, 1953.