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Tactical opportunities, risk attitude and choice of farming strategy: an application of the distribution method[†]

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When assessing farming strategies, it is important to account for the opportunities provided for tactically adjusting to outcomes of risk. The hypothesis that accounting for tactical adjustment is more important than accounting for risk attitude was supported in this study with regard to identifying the optimal drainage recirculation strategy for an irrigated dairy farm. Failing to account for tactical adjustment would lead to a sub-optimal choice, costing the farmer about A$3 100 in present value terms. In contrast, failing to account for risk aversion would not affect the strategy chosen. The distribution method was found to be well suited to modelling tactical adjustment.

1. Introduction

Farmers operate in a risky environment. Regardless of whether they are averse to risk, prefer it or are ambivalent about it, they tactically adjust their farming strategies as the outcomes of risk relating to seasonal conditions, prices, and so on become known (Antle 1983). However, only recently has the importance for strategic choice of accounting for the opportunities provided by each strategy to tactically respond to outcomes of risk attracted much attention from agricultural economists (Hardaker, Pandey and Patten 1991; Kingwell, Pannell and Robinson 1993; Pannell, Malcom and Kingwell; 1995). Priority with respect to analysing risky decisions has been placed mostly on accounting for the effect of attitude to risk on choice of farming strategy (Kingwell *et al.* 1993; Pannell *et al.* 1995).

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Pannell *et al.* (1995, p. 9) have recently gone so far as to hypothesise that 'the benefits of including tactical response options in a farm model are often, if not usually, greater than the benefits of including risk aversion'. This is consistent with findings by Kingwell *et al.* (1993) and Kingwell (1994) for farmers in the eastern wheat belt of Western Australia. In the former study it was found that modelling tactical adjustment resulted in identification of an optimal farming strategy expected to be 20 per cent more profitable than the strategy which would otherwise have been identified. In the latter study, in contrast, modelling risk aversion was found to result in identification of an optimal strategy that was only 2 to 6 per cent more profitable than the strategy that would otherwise have been identified. Kingwell *et al.* (1993) warned that optimal farming strategies may be wrongly identified as a result of ignoring the benefits and costs of tactical choices allowed by strategies being evaluated.

Given a continuing interest in analysing risky agricultural decisions, the fact that the hypothesis quoted above challenges 'traditional practice' in such analysis, and that there are few studies on the topic, there is a pressing need to undertake further studies capable of providing observations suitable for testing this particular hypothesis.

A request to evaluate the economics of drainage recirculation and storage strategies for irrigated dairy farms in the Berriquin Irrigation District (Berriquin) provided a timely opportunity to meet this need. The request arose from a need to evaluate various on-farm options prior to their inclusion in a 'land and water management plan'. The District lies near Deniliquin in southern inland New South Wales. Availability of water for irrigation in Berriquin varies from year to year with variation in the percentage of base volumetric allocation allowed to be utilised,[1] off-allocation flows (use of which is priced as for allocation water but not debited against allocation), and rainfall. Berriquin dairy farmers have an array of tactical responses from which to choose, depending on water availability, including variation of areas of pasture irrigated, intensity of irrigation per hectare, off-allocation volume utilised, and temporary leasing in of portions of other farmers' allocations (or leasing out of their own). These tactical options provide considerable scope for ameliorating losses of profitability in years of low water availability and capturing additional profits in years of high water availability.

Installation of a drainage recirculation system, with or without a water storage capacity, provides a Berriquin dairy farmer with further such tactical

[1] The percentage of base allocation granted in any year depends primarily upon the volume of water in the major storages for the Murray Valley (Hume and Dartmouth Dams) at the commencement of the irrigation season (late August to early September).

options. It allows runoff from irrigation to be stored for later use or to be recirculated within the current irrigation. Runoff from rainfall also can be stored for later use. Off-allocation flows arriving when water is not required for irrigation can also be stored for later use. The extent to which these options can be exercised depends on the recirculation strategy chosen, particularly with respect to the capacity of the chosen system to store water.

The primary aim of the study was to determine the optimal drainage recirculation strategy for a representative Berriquin dairy farmer. The associated aim was to ascertain the degree to which accuracy in this task depended on account being taken of tactical adjustment and risk attitude. The rationale for modelling tactical adjustment is addressed first. Since the reason for tactical adjustment being modelled so rarely is the difficulty of doing so (Hardaker *et al.* 1991), particular attention is then given to the distribution method used in the study to overcome this problem. After detailing the particulars of the model developed, and outlining the recirculation strategies examined, the decision criteria used for the risk averse and risk neutral cases, respectively, are discussed. The optimal strategy given each decision criterion is then revealed and, finally, a conclusion is reached regarding whether the findings support the hypothesis that the benefits of accounting for tactical adjustment activities in a farm model are often greater than the benefits of accounting for risk aversion.

2. Why model tactical response to varying water availability?

It follows from the law of diminishing returns that the benefit arising per megalitre (ML) of water provided by a recirculation system, given by its marginal value product, declines as the availability of water from prior sources, namely allocation, off-allocation and rainfall, increases. Stochastic availability of water from these prior sources results in uncertainty regarding the benefit that will arise per megalitre of water supplied by a recirculation system.

The use of expected values of allocation, off-allocation and rainfall instead of the full probability distributions corresponding to these variables would allow a deterministic evaluation of recirculation. However, given that a production function consistent with the law of diminishing returns is concave to the origin, the use of the expected value of water supply from prior sources to predict the expected level of output in the absence of recirculation will result in the latter being overestimated and, assuming a fixed output price, the expected marginal value product of water supply therefore being underestimated. Since the expected annual benefit from the additional water made available by a recirculation system is given by its expected marginal value product, this benefit would be underestimated in a deterministic evaluation.

The deterministic approach is frequently followed in agricultural decision analyses given its relatively low cost and the expectation that errors in estimating benefits are small if the production function is concave to only a minor degree within the relevant range of input levels, and/or the relevant range of input levels is sufficiently narrow that the concavity of the production function results in only minor inaccuracy.

However, the last criterion does not apply in the case of water supplies, particularly allocation supplies, in Berriquin. The Murray Basin Planning Simulation Model, incorporating historical streamflow data from 1892 to 1987, was used to estimate a frequency distribution for allocation percentage given existing infrastructure and institutional arrangements (Murray-Darling Basin Commission, undated). The range of the distribution extends from 140 per cent of allocation to 0 per cent. The distribution is highly negatively skewed, with a mean of 119 per cent. There is likely to be a considerable difference between the relatively large benefit per megalitre of water made available by a recirculation system in rare 'low allocation percentage' years and the relatively low benefit per megalitre in the predominant 'high allocation percentage' years.

This reasoning was borne out in discussions with Berriquin farmers and irrigation extension officers who indicated that the additional water provided by a recirculation system in general confers little benefit when allocation percentage is above its mean level but confers significant benefits when allocation percentage is below its mean. A deterministic evaluation would, therefore, likely result in the expected annual benefit from a recirculation system being significantly underestimated.

3. Modelling tactical adjustment

Analysis of the benefits of a particular recirculation strategy represents a sequential decision problem wherein an initial strategic decision is made, uncertain states of nature sequentially become revealed at l stages and tactical decisions, which are conditioned by both the strategic choice and the revealed outcomes, are available at least at one of these stages.

Hardaker *et al.* (1991) refer to this type of decision problem as one involving embedded risk. The tool most often used to analyse such a problem has been discrete stochastic programming (Cocks 1968). For instance, this technique was used by Kingwell *et al.* (1993). Rae (1977, p. 454) commented that 'the expected net benefit from solving a discrete stochastic program might have to be considerable to outweigh the costs of data collection and model construction, testing and solution'. However, these costs are being reduced with progress in computing hardware and mathematical programming software (Hardaker *et al.* 1991).

Another, though little-used, tool for analysing problems involving embedded risk is the 'distribution method', applied first by Johnson *et al.* (1967). The distribution method can be elucidated using the following formulation of a linear programming model:

$$\text{Maximise } z = \sum_{j=1}^{m} c_j x_j$$

$$\text{subject to } \sum_{j=1}^{m} a_{ij} x_j \leq b_i$$

where z is the total payoff from all activities, c_j is the payoff from the jth activity ($j = 1, \ldots, m$), x_j is the level of the jth activity, a_{ij} is the amount of the ith resource required by the jth activity and b_i is the supply of the ith resource (Dent *et al.* 1986).

In applying the distribution method, all of the elements c_j, a_{ij} or b_i may, if required, be specified as stochastic. If the stochastic variables are observed *before* selecting the decision vector, then the problem to be solved is a deterministic linear programming problem. The objective function of the linear program can now be represented as:

$$\text{Maximise } F(c_j, a_{ij}, b_i) = \text{Maximise } \sum_{j=1}^{m} c_j x_j$$

Since at least one of the elements of c_j, a_{ij} or b_i is stochastic, $F(c_j, a_{ij}, b_i)$ will have a probability distribution. If a set of variates (c_j^*, a_{ij}^*, b_i^*) are sampled from the probability distributions for the random elements in c_j, a_{ij} or b_i and are substituted for the stochastic parameters in the model, the deterministic solution value of $F(c_j^*, a_{ij}^*, b_i^*)$ is a variate from the probability distribution $F(c_j, a_{ij}, b_i)$. By repeatedly sampling sets of variates and solving the linear program for each set, the distribution for $F(c_j, a_{ij}, b_i)$ can be estimated, the number of sets to be sampled depending upon the precision with which $F(c_j, a_{ij}, b_i)$ is to be approximated. Johnson, Tefertiller and Moore (1967, p. 911) noted that the 'only operational difficulty presented by the distribution method is associated with the procedure for obtaining sets of random variates from the assumed probability distributions'. They were limited to sampling only 20 sets of variates.

Rae (1970) noted a second possible problem when the distribution method is applied to capital budgeting problems. If investment activity levels are modelled as decision variables, optimal levels of these activities may vary from one solution to another according to the values drawn for random variables. This assumes, often unrealistically, that investment decisions are tactical rather than strategic. A third limitation of the distribution method, inferred by Rae (1971), is that it assumes the decision-maker has perfect knowledge of what the random variates will be.[2] These three types of problems are presumably what Barnard and Nix (1979, p. 432) had in mind when suggesting that the very limited use of the distribution method had been due to 'practical difficulties in its application'.

However, each of these problems can be resolved. First, increases in computing power and availability of software such as @RISK™ (Palisade Corporation 1992) now allow hundreds of sets of random variates to be sampled in a matter of minutes, regardless of the types of probability distributions specified, in attempting to estimate $F(c_j, a_{ij}, b_i)$. It is also possible to account for correlation among the stochastic variables. Furthermore, multiple runs of a linear program with successive sets of variates can now easily be automated, for example by writing a spreadsheet macro.

Second, the problem of accounting for strategic decisions such as relating to investment activity levels can be resolved by fixing these decisions prior to solving the distribution problem. However, the distribution method cannot then be used to automatically identify the optimal strategy. Rather, it can be used to simulate how a decision-maker would tactically respond to outcomes of uncertain events if a particular strategy were to be implemented. The outcomes of all available strategies can be simulated similarly.

Third, it is clearly unreasonable to assume that the values of all stochastic parameters are known at the commencement of the period covered by the linear program if some of the uncertainty does not unfold until afterwards. Where all relevant uncertainty unfolds no later than the commencement of the period represented by the model, however, it is valid to use the distribution method to simulate how a farmer would tactically respond at the beginning of each period.

In cases where all uncertainty regarding relevant events cannot reasonably be assumed to be resolved at the start of the period covered by the linear program, the distribution method could be adapted to account for tactical responses available during the period represented by the model. This would require writing a computer program so that the linear program is re-run at discrete stages during the full period. At each stage the linear program would

[2] Although Rae was in fact referring to a different type of stochastic programming formulation, his comments apply equally to the distribution method.

be run with (a) random variates inserted for the events assumed to be already resolved; (b) forecast values inserted for the yet-to-be-resolved random variables; and (c) decision variables limited to those relating to the tactical responses available at that stage and not precluded by tactical responses chosen at the preceding stage(s).

Thus the main shortcoming of the distribution method is that it does not automatically identify the optimal strategy. However, if the number of candidate strategies can be culled by prior analysis, the task of parametrically searching for the optimal strategy can be reduced considerably.

Another possible shortcoming of the approach is that the computing time for evaluating a particular strategy can be lengthy, at least compared with running a discrete stochastic programming model. To obtain a reasonable approximation of $F(c_j, a_{ij}, b_i)$, it may be necessary to re-run the distribution method linear program for 200 or 300 sets of variates drawn from the probability distributions of the variables specified as stochastic. Using a 66 MHz 486 computer, it took about two hours to apply the distribution method for this study with 200 different sets of random variates.

The distribution method nevertheless has a number of attractive features. These include:

(i) only minor modifications, if any, from the linear program are required for a deterministic formulation of the problem. Modifications may be required to include tactical decision variables that would not otherwise be included in the deterministic formulation.
(ii) Stochastic parameters can be represented using continuous distributions of any kind, thus enabling accurate representation of probability distributions.
(iii) Covariability among stochastic parameters can be accounted for by using functions available in @RISK.™
(iv) Recursive effects from one period covered by the distribution method linear program to the next can be represented by treating each farm plan, based on a unique set of random variates, as part of a chronological sequence. For example, the optimal stocking rate for the farm plan associated with one set of random variates can be automatically inserted as a state variable into the distribution method linear program for the run of the model into which the next sample of random variates is to be inserted.

On the basis of these positive features and also the fact that the number of candidate strategies was relatively small, the distribution method was considered to be the most appropriate approach for this study.

4. Modelling approach

The irrigation supply network of Berriquin is normally operative from August of one year until May of the next (being emptied in the remaining period to allow refurbishment). The allocation percentage for the irrigation season ahead is normally known by the end of September. The representative farmer was therefore assumed to make all tactical decisions at the end of September based on the allocation percentage, rainfall and off-allocation availability over August and September, and expected values of rainfall and off-allocation availability for subsequent months (i.e., October to May).

The subjective probability distribution of the representative farmer regarding allocation percentage was assumed to accord with the relative frequency distribution for allocation percentage as derived from output of the Murray Basin Planning Simulation Model.

The volume of off-allocation water that could be accessed per month was assumed to be limited to 450 megalitres due to physical restrictions on inflow to the farm. The hydrology simulation model was also used to estimate relative frequency distributions regarding monthly off-allocation availabilities, upon which the farmer's probability distributions for these variables were assumed to be based. These probabilities, represented using a binary discrete function (i.e., either 450 or 0 megalitres of off-allocation is available per month), are shown in table 1. For August and September, the probability distributions for off-allocation availability were specified in the stochastic simulation model. For the subsequent months, October to May inclusive, off-allocation volumes were set at the expected values of the relevant distributions.

Daily rainfall data for the town of Finley (located within Berriquin) over the period 1968 to 1992 were used to derive relative frequency distributions for daily rainfall in each month, upon which the farmer's probability distributions for these variables were assumed to be based. These probability distributions were used in estimating monthly volumes of rainfall runoff available for recirculation. For the months October to May inclusive, rainfall runoff values were set at the expected values of the relevant distributions. For the months June to September inclusive, the probability distributions for

Table 1 Probability of monthly off-allocation availability

Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
0.56	0.60	0.45	0.28	0.13	0.01	0.00	0.00	0.04	0.16

Table 2 Mean monthly rainfall runoff for the representative dairy farm (ML)

Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
0.32	0.29	0.31	1.10	1.17	2.45	0.89	0.53	1.35	0.52

rainfall runoff were specified in the stochastic simulation module. The method of estimating runoff volumes from rainfall is detailed in Wall *et al.* (1994). The significance of rainfall runoff for irrigation water supply can be gauged from table 2.

Given that the base irrigation allocation for a typical dairy farm in Berriquin is around 600 megalitres, it is evident that, in an average year, rainfall runoff makes only a minor contribution to irrigation water supply. Hence it is unlikely that the accuracy of estimating the benefits from a recirculation system would be increased significantly by including decision stages subsequent to the end of September so as to more comprehensively account for tactical responses to rainfall runoff events.

An important point to consider when conducting stochastic simulations is the degree of covariability among the stochastic variables. The coefficient of correlation between allocation percentage and off-allocation availability was, at 0.08, found not to be significantly different from zero. This lack of a positive correlation is explained by (a) off-allocation supplies originating from flows in tributaries that enter the Murray River below the storage headworks from which allocation flow emanate, and (b) climatic conditions experienced in the catchments of the tributaries differing from those in the catchments of the headworks.

Both allocation and off-allocation supplies were expected to be independent of rainfall in Berriquin for both spatial and temporal reasons. The District is located about 400 kilometres to the west of the storage headworks in the upper catchments and therefore experiences different weather patterns. In addition, rainfall is experienced by farmers in the current period whereas headworks storage levels are governed by rainfall in the upper catchment in previous seasons.

Since allocation percentage for an irrigation season is largely governed by storage levels in headwork dams at the commencement of the season, and these storage levels necessarily are serially correlated, autocorrelation between allocation percentage in consecutive years was expected. This expectation was borne out by a serial correlation coefficient of 0.43, which was found to be significantly greater than zero.

To summarise, the distribution method as applied in this study was as follows:

(i) A linear program was developed to determine the farm plan (i.e., levels of tactical activities) that maximises total gross margin within an irrigation season given a strategic decision to install the k^{th} of the recirculation system options (as discussed below, seven options, including one of not installing any system, were compared).

(ii) A stochastic simulation model was designed using a spreadsheet and @RISK™ stochastic simulation software, in which probability distributions for, and covariability among, the parameters to be treated as stochastic were specified. These parameters were allocation percentage, August and September off-allocation availability and August and September rainfall. Autocorrelation between allocation percentage in consecutive years was also specified. Formulae were specified within the simulation model to derive variates of each parameter of the linear program corresponding to the random variates drawn from these distributions (i.e., from the primary variates). The number of sets of primary variates to be sampled during a simulation was specified (200 sets in this study).

(iii) A spreadsheet macro was written which, after the n^{th} set of primary variates was sampled:
  (a) copied each variate as a point value to the appropriate location in the linear program;
  (b) initiated the solving of the linear program (using What's Best!™ (Savage 1992) spreadsheet-based software);
  (c) recorded the total gross margin of the farm plan found to be optimal given this set of variates; and
  (d) initiated the sampling of the next set of variates and repeated steps (a) – (c) until the number of sets of variates specified in step (ii) had been drawn.

  The macro also accounted for recursive relationships between optimal activity levels in one linear programming solution and feasible activity levels in the following solution. Finally, the @RISK™ software derived a probability distribution for total gross margin given all the observations of the variable recorded cumulatively in step (c).

(iv) The first recirculation strategy to be evaluated was specified within the simulation model and the spreadsheet macro was run.

(v) Step (iv) was repeated for the other recirculation strategies.

(vi) The cumulative density functions for total gross margin derived for each of the recirculation strategies were used as the basis for choosing among them. The choice criteria used in this study are discussed below.

This method is illustrated in figure 1.

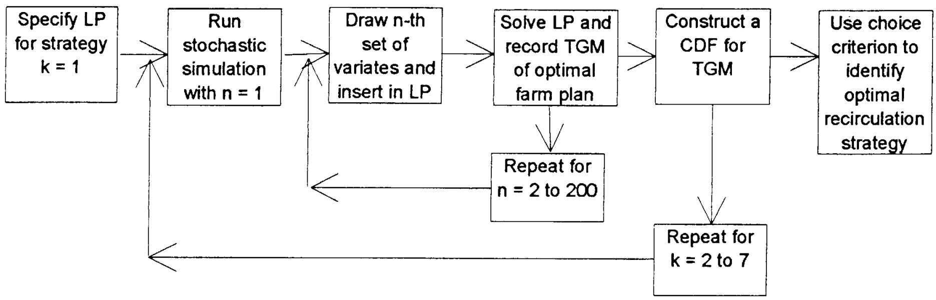

Figure 1 Modelling approach used in this study

5. The model

A full specification of the linear program is available in Wall *et al.* (1994). In summary, the area of the typical Berriquin dairy farm was assumed to be 220 hectares, of which 88 hectares is laser landformed. The base irrigation allocation was assumed to be 608 megalitres per year.

Pasture activities modelled were irrigated annual and perennial pastures and non-irrigated annual pasture. Low- and high-input irrigated annual pasture activities were differentiated, with irrigation intensity being lower in the former case. Cropping was assumed not to be undertaken. An annual market quota of 442 000 litres, allowing sales of up to this volume to the premium-priced 'fresh' milk market, was assumed. Over-quota production could be sold to the lower-priced market for 'manufacturing milk'. Each cow was assumed to produce 5 300 litres of milk a year. The existing milking shed was assumed to limit herd size to 264 milking cows.

Irrigation water requirements per hectare and irrigation runoff per hectare for the various pasture activities were specified on a monthly basis. Ability to meet monthly irrigation requirements was constrained by annual allocation, off-allocation availability, ability to store and carry forward water becoming available in preceding months (i.e., from off-allocation and runoff from irrigation and rainfall) and on the volume that the farm can physically receive from the district supply system per month (noted above to be 450 megalitres per month). A tie constraint requiring that all water stored be reused within the same year was included since Berriquin farmers generally fully utilise water in their storages by the end of the irrigation season to avoid seepage losses over the winter.

Possibilities for Berriquin dairy farmers to tactically respond at the end of September to outcomes revealed by that time relating to allocation percentage, off-allocation availability and rainfall were accounted for in the linear program through inclusion of the following decision variables:

- lease in additional units of water allocation (assumed to be limited to 100 megalitres);
- lease out units of water allocation;
- convert high-input annual pasture to low-input annual pasture (and vice versa);
- convert low-input annual pasture to non-irrigated annual pasture (and vice versa);
- make silage or hay;
- feed out silage or hay;
- buy or sell hay;
- buy grain for feed;
- purchase off-allocation water in month *i*;
- irrigate with off-allocation water in month *i*;
- store off-allocation water in month *i*;
- recirculate irrigation runoff in month *i*;
- store irrigation runoff in month *i*;
- store rainfall runoff in month *i*;
- irrigate in month *i* using stored water;
- release runoff to district drains in month *i*; and
- release stored water to district drains in month *i*.

In total, the linear program included 402 activities and 478 constraints. The model was validated by exposing its inputs, as well as outputs regarding pasture and livestock activity levels and volumes of water recirculated, stored and disposed of into district drains, for scrutiny by agronomists, irrigation officers and farmers involved in identifying and appraising on-farm options for inclusion in the Berriquin land and water management plan. The process of reaching a 'validation consensus' involved a series of meetings with these parties convened by the officer responsible for overseeing evaluations of on-farm options. The meetings, and consequent reformulations of the model, took place over a period of four months. This approach was necessary due to a lack of historical farm-level data with which to 'objectively' validate the model, particularly with regard to volumes of water recirculated, stored and disposed of into district drains.

6. Recirculation strategies examined

Recirculation and storage systems can vary greatly in capacity and in capital, pumping and maintenance costs. Details of the six systems considered are presented in table 3. A benchmark (no recirculation system) strategy was

Table 3 Details of drainage recirculation systems evaluated

Storage capacity (ML)	Area of storage (ha)	Capital cost ($)	Pumping cost ($/ML)	Annual maintenance cost ($)
3	0.0	17 000	2.03	683
8	0.2	20 090	2.03	683
13	0.7	29 000	2.25	683
29	1.6	33 560	3.15	833
51	2.4	42 980	3.26	833
79	3.3	53 720	3.33	833

also considered. The design of systems was assumed to be such that water is pumped into storage and is discharged from storage under gravity.

Although the first strategy does not incorporate a separate storage, interlinking of paddock channels and drains in this strategy (and in all recirculation strategies) enables their use for storing up to three megalitres of water. The storage for the second strategy (eight megalitres capacity including channels and drains) was assumed to be a sump (a section of drain made deeper and wider than normal). The storage for the third strategy (13 megalitres capacity including channels and drains) was assumed to be a square dam. The remaining storages were assumed to be of ‘turkey nest’ construction, whereby earth excavated from within the storage area is used to build the walls.

Capital costs of strategies include costs of installing pumps and fixtures and of earthworks involved in excavating storages, interlinking paddock drains and constructing a raised channel to enable return of drainage by gravity from the storage (or pump site in the case of the first strategy) to the farm supply system. Recirculation pumps for all systems were assumed to be constrained to pumping 300 megalitres per month. The opportunity cost of the land area devoted to a storage was accounted for by reducing the available land area limit in the linear program accordingly.

7. Choice criteria

Depending on whether the farmer was assumed to be risk neutral (and therefore indifferent to probability distribution moments other than expected value) or risk averse, the criterion by which the financial outcomes of each of the recirculation strategies were compared related, respectively, to the expected value or the cumulative density function for net present value (NPV) of farm net cash flow.[3] Calculation of net cash flow did not account

[3] Hereafter referred to simply as net cash flow.

for overhead costs, other than the cost of annual recirculation system maintenance, which are constant across strategies. Items accounted for in the calculation of net cash flow were total gross margin (which incorporates recirculation pumping costs), capital cost of recirculation system installation and the recurrent cost of maintaining a system. It was assumed that the planning horizon is 30 years and the annual discount rate is 15 per cent. The discount rate was chosen as representative of Berriquin dairy farmers' real opportunity cost of capital at a time when the demands on their capital, for implementing an extensive array of land and water conservation technologies, were high. Strategies with NPVs exceeding zero were deemed to be economically attractive to the representative farmer.

7.1 Risk-neutral case

The expected value of NPV given a particular recirculation strategy was obtained by setting net cash flow at its expected value for all 30 years of the planning horizon. To enable assessment of the empirical significance of accounting for tactical responses to embedded risk, rather than ignoring it, the expected value of the NPV of a recirculation strategy was calculated twice, first using expected net cash flow as obtained using the distribution method and, second, using expected net cash flow as obtained using a standard linear program. In either case the optimal recirculation strategy for the risk-neutral case was the one with the highest expected NPV.

7.2 Risk-averse case

The cumulative density function for total gross margin given a particular recirculation strategy was available from having applied the distribution method. The cumulative density function for annual net cash flow could then be obtained by subtracting the annual maintenance cost of the recirculation strategy from total gross margin.

Cumulative density functions for net cash flow for all years of the planning horizon were assumed to be identical and not autocorrelated. An observation for the NPV associated with a particular recirculation strategy could thereby be obtained using each set of 30 random variates of net cash flow to represent a series of annual values that could occur within the planning horizon. A cumulative density function for NPV could thus be generated by repeating this process 200 times using @RISK™.

Application of expected utility theory to guide choice between decision alternatives for a risk-averse farmer requires that the degree of risk aversion be precisely known. Given that measurement of risk preference is subject to large errors (King and Robison 1981; Schoemaker 1982), stochastic efficiency rules, which satisfy the axioms of expected utility theory without requiring precise measurement of risk preference, have been developed as a practical alternative. However, these rules provide only a partial ordering of decision alternatives as opposed to the complete ordering when precise measurements of risk preference are available (Pandey 1990).

Stochastic efficiency rules are applied by undertaking pairwise comparisons of cumulative density functions. The rule used in this study was stochastic dominance with respect to a function (Meyer 1977a, b). This rule is based on a proof that the coefficient of absolute risk aversion, $r(x)$, represents risk preferences uniquely, where $r(x)$ is given by the negative ratio of the second and first derivatives of the utility function, $u(x)$ (Pratt 1964). The rule requires only that upper and lower bounds on $r(x)$ be set; its discriminatory power depends on the width of the range between the upper and lower bounds.

A maximum range of 0.5 (risk-neutral) to 4 (extreme risk-aversion) for the coefficient of relative risk aversion, $r_R(x)$, has been suggested by Anderson and Dillon (1991), with the recommended range in developed countries being between 1 and 2. The coefficient of relative risk aversion is related to $r(x)$ by the function:

$$r(x) = r_R(x)/w$$

where w represents net wealth. An idea of the relevant range of values of $r(x)$ likely to be applicable for a Berriquin dairy farmer was obtained by parametrically varying values of $r_R(x)$ and w over realistic ranges for each. Values of 1, 2 and 3 for $r_R(x)$ were used. The value of assets of a dairy farm of the size modelled in this study was estimated to be \$800 000. The associated net wealth of the farmer was estimated under three scenarios:

(i) 70 per cent equity ratio and no ownership of off-farm assets ($w =$ \$560 000);
(ii) 100 per cent equity ratio and no ownership of off-farm assets ($w =$ \$800 000); and
(iii) 100 per cent equity ratio and outright ownership of off-farm assets valued at \$700 000 ($w =$ \$1 500 000).

The resulting subset of 'relevant' values of $r(x)$ is presented in table 4.

Table 4 Relevant values of $r(x)$ for a Berriquin dairy farmer

	Net wealth		
r_R	\$560 000	\$800 000	\$1 500 000
1	1.8×10^{-6}	1.3×10^{-6}	6.7×10^{-7}
2	3.6×10^{-6}	2.5×10^{-6}	1.3×10^{-6}
3	5.4×10^{-6}	3.8×10^{-6}	2.0×10^{-6}

Based on table 4, it was concluded that the relevant range of $r(x)$ for a Berriquin dairy farmer of the size modelled in this study is bounded by 6.0×10^{-7} and 6.0×10^{-6}. In order to ascertain whether there is any variation in the risk-efficient set of recirculation systems within this range, the stochastic dominance with respect to a function rule was applied using two sections of this range: (a) 6.0×10^{-7} to 1.2×10^{-6}; and (b) 1.2×10^{-6} to 6.0×10^{-6}. The computer program Generalised Stochastic Dominance (Raskin and Cochran 1986) was used for this purpose.

The use of linear programming for modelling tactical decisions implies that farmers are risk neutral with respect to these decisions. There is thus an apparent inconsistency between assuming that a farmer is risk neutral with respect to tactical decisions and assuming s/he is risk averse with respect to strategic decisions relating to investment in a recirculation system. However, intuition suggests that risk aversion is more significant in influencing the choice between strategies involving substantial investment outlays than in influencing recurring tactical choices, and therefore that any bias resulting from this inconsistency will be small.

8. Results: risk-neutral case

In table 5 the expected NPV of net cash flow for each strategy as calculated using linear programming can be compared with the expected NPV as calculated using the distribution method. The expected NPV of each strategy as obtained from using a linear program and the distribution method respectively can also be compared. The NPV of a recirculation strategy is given by subtracting the NPV of the net cash flow associated with the 'no recirculation system' strategy from the NPV of the net cash flow associated with the recirculation strategy. The ranking of strategies according to NPV of net cash flows is of course identical to that obtained on the basis of NPV of strategies.

Expected NPV of net cash flow is greater in all cases when estimated deterministically using linear programming than when stochastically estimated using the distribution method. This accords with the earlier observation that, given the law of diminishing returns, setting water input levels at their expected values will result in expected output being overestimated. The distribution method, by accounting for tactical adjustment of water input levels, aims to remove this bias.

Furthermore, expected NPV of each recirculation strategy is also significantly greater when estimated accounting for variability of water supply by using a stochastic approach such as the distribution method. This accords with the earlier observation that setting water input levels at expected values will, by overestimating expected output, lead to underestimation of the marginal value product of water supply. That is, the

Table 5 Results from evaluating recirculation strategies

Strategy	Expected NPV of net cash flow ($)		Standard deviation of net cash flow ($)	Skewness of net cash flow	Difference in expected NPV compared with no recirculation system ($)	
	Linear program	Distribution method			Linear program	Distribution method
No recirculation system	1 335 783	1 268 091	59 476	– 0.74		
Recirculation system with:						
3 ML storage	1 323 550	1 264 139	55 748	– 0.69	– 12 233	– 3 952
8 ML storage	1 340 230	1 278 693	54 224	– 0.66	4 447	10 602
13 ML storage	1 347 039	1 283 892	52 458	– 0.82	11 256	15 802
29 ML storage	1 363 950	1 300 430	49 687	– 0.76	28 167	32 339
51 ML storage	1 363 151	1 303 517	48 885	– 0.69	27 368	35 427
79 ML storage	1 361 413	1 301 484	47 615	– 0.65	25 630	33 393

value of the marginal additions to water supply due to a recirculation system would have been significantly underestimated had not the stochastic nature of water supply been modelled. The linear programming and distribution method approaches result in the strategies with 29 and 51 megalitres of storage capacity being identified, respectively, as optimal for a risk-neutral farmer. The fact that a strategy with greater storage capacity was identified as optimal using the stochastic approach, when compared with that identified using the deterministic approach, is consistent with the former approach attributing a higher marginal value product to water supply.

The bias caused by ignoring embedded risk would therefore have led to the wrong recirculation strategy being identified as optimal. The present value of the cost of ill-informedly adopting the 29 megalitres strategy rather than the 51 megalitres strategy is A$3 088, given by subtracting the NPV of the 29 megalitres strategy from the NPV of the 51 megalitres strategy when both are obtained using the distribution method. Put another way, it would have been worthwhile for the farmer to pay an adviser up to A$3 088 extra to use the distribution method to account for the tactical advantages from recirculation, when the alternative is that these advantages be ignored by using a linear program.

8.1 Risk-averse case

Given an expected value for profitability (or wealth), the utility of a risk-averse farmer is increased by reducing the standard deviation or, typically, the negative skewness of the associated probability distribution. Hence in order to investigate how a risk-averse farmer would choose between the various recirculation strategies, the standard deviation and relative skewness of NPV of farm net cash flow associated with each strategy, as calculated using the distribution method, are shown in table 5.

Standard deviation of the NPV of net cash flow is seen to decline with installation of a recirculation system and to decline consistently further with increases in system storage capacity. Negative skewness is lessened, compared with the base situation, by installing the recirculation system with 3 megalitres storage capacity, but it is lessened more by installing the system with 8 megalitres capacity. Although installation of the system with 13 megalitres capacity increases negative skewness relative to the base situation, systems progressively larger than this result in a progressive lessening of negative skewness. Nevertheless, negative skewness for the system with 29 megalitres capacity is greater than that for the base situation.

For a farmer whose utility is increased by reducing standard deviation or negative skewness, *ceteris paribus*, the recirculation systems with 51 and 79 megalitres storage capacity clearly dominate the remainder. The choice

Table 6 Risk-efficient sets of recirculation strategies for two ranges of $r(x)$

$r(x)$	Risk-efficient set
6.0×10^{-7} to 1.2×10^{-6}	51 ML
1.2×10^{-6} to 6.0×10^{-6}	51 ML

ultimately depends on the strength of the preference for increased expected value, since the 51 megalitres option is superior by this criterion but inferior in terms of standard deviation and skewness. Resolution of this trade-off requires either specification of the utility function or application of stochastic efficiency criteria.

The risk-efficient sets of recirculation strategies corresponding to two alternative ranges of $r(x)$ are shown in table 6.

For both ranges of $r(x)$ the risk-efficient set contains only the 51 megalitres option. This is the same option identified as optimal when the farmer was assumed to be risk neutral. In order to ascertain the sensitivity of the optimal option to values of $r(x)$ signifying greater absolute risk aversion than represented in the above ranges, the upper bound was extended incrementally until there was a change in the risk-efficient set. Once the upper bound exceeded 1.2×10^{-5}, the risk-efficient set expanded to include the 79 megalitres option.

The likelihood of a Berriquin dairy farmer being as averse to risk as this can be gauged by solving for the level of wealth that is consistent with this level while assuming that $r_R(x)$ is equal to 3 (which is as high as could be reasonably be expected according to Anderson and Dillon 1991). This calculation yields a value of A\$250 000 for net wealth. Given that the assets of a farm of the type chosen as representative were estimated to be worth A\$800 000, net wealth of A\$250 000 corresponds with an equity ratio of 31 per cent. Since a farm business with such a low equity ratio is most unlikely to have survived, it can reasonably be concluded that the risk-efficient set is limited to the recirculation strategy with 51 megalitres of storage.

Identification of the optimal recirculation strategy was thus found to be insensitive to whether risk aversion within realistic bounds was accounted for in the analysis. It would not have been worthwhile for the farmer to pay a consultant anything at all to account for risk attitude in modelling this decision problem.

9. Conclusions

All strategies involving installation of a recirculation system, other than the one with the lowest (3 megalitres) water storage capacity, were found to be economically superior to the strategy of not installing a system. For the case where the representative Berriquin dairy farmer was assumed to be risk neutral, the optimal recirculation strategy was found to be installation of a system with a storage capacity of 51 megalitres.

This optimal strategy is not the one that would have been identified in the risk-neutral case if the scope that each recirculation strategy affords for tactically adjusting the farm plan from year to year in response to variability in water availability had been ignored. It was estimated that the net present value of the strategy that would wrongly have been identified as optimal (the one with a storage capacity of 29 megalitres) would be about A$3 100 lower than the 'correct' optimal strategy. This can be viewed as the cost to the farmer of basing a choice regarding recirculation strategy on an analysis that neglects the tactical advantages afforded by each strategy. In contrast, the optimal strategy was found not to change if the farmer, instead of being risk neutral, was assumed to be averse to risk within realistic bounds. Hence there would be no cost to the farmer in this case from basing a choice on an analysis that assumes risk neutrality.

The findings of the study thus add support to the hypothesis of Pannell *et al.* (1995, p. 9) that benefits in decision analysis from accounting for tactical adjustment 'are often, if not usually, greater than the benefits of including risk aversion'. By reducing the difficulty of accounting for tactical adjustment in modelling choices of farming strategy, the distribution method used in this study offers scope for reversing the situation to date wherein tactical adjustment has only rarely been accounted for.

The focus in this article has been on investigating this hypothesis rather than on providing advice to Berriquin dairy farmers regarding whether they should adopt a recirculation strategy. Sensitivity testing with respect to additional key parameters, particularly discount rate and milk price, would be required if this second task were to be thoroughly performed. Finally, the study accounted only for private benefits and costs. Decisions regarding the social desirability of the various recirculation strategies would need to account also for the external costs and benefits of the strategies.

References

Anderson, J.R. and Dillon, J.L. 1991, *Guidelines on Incorporating Risk in Farming Systems Analysis for the Development of Dryland Areas*, FAO of the United Nations, Rome.

Antle, J.M. 1983, 'Sequential decision-making in production models', *American Journal of Agricultural Economics*, vol. 65, no. 2, pp. 282–90.

Barnard, C.S. and Nix, J.S. 1979, *Farm Planning and Control*, 2nd edn, Cambridge University Press, Cambridge.

Cocks, J.D. 1968, 'Discrete stochastic programming', *Management Science*, vol. 15, no. 1, pp. 72–9.

Dent, J.B., Harrison, S.R. and Woodford, K.B. 1986, *Farm Planning with Linear Programming: Concept and Practice*, Butterworths, Sydney.

Hardaker, J.B., Pandey, S. and Patten, L.H. 1991, 'Farm planning under uncertainty: a review of alternative programming models', *Review of Marketing and Agricultural Economics*, vol. 59, no. 1, pp. 9–22.

Johnson, S.R., Tefertiller, K.R. and Moore, D.S. 1967, 'Stochastic linear programming and feasibility problems in farm growth analysis', *Journal of Farm Economics*, vol. 49, no. 4, pp. 908–19.

King, R.P. and Robison, L.J. 1981, 'An interval approach to measuring decision maker preference', *American Journal of Agricultural Economics*, vol. 63, no. 3, pp. 510–20.

Kingwell, R.S. 1994, 'Risk attitude and dryland farm management', *Agricultural Systems*, vol. 45, pp. 191–202.

Kingwell, R.S., Pannell, D.J. and Robinson, S.D. 1993, 'Tactical responses to seasonal conditions in whole-farm planning in Western Australia', *Agricultural Economics*, vol. 8, pp. 211–26.

Meyer, J. 1977a, 'Choice among distributions', *Journal of Economic Theory*, vol. 14, no. 2, pp. 326–36.

Meyer, J. 1977b, 'Second degree stochastic dominance with respect to a function', *International Economic Review*, vol. 18, no. 2, pp. 477–87.

Murray-Darling Basin Commission (undated), Murray Basin Planning Simulation Model, unpublished documentation, Murray-Darling Basin Commission, Canberra.

Palisade Corporation 1992, *@RISK: Risk Analysis and Modelling: Release 1.1 User's Guide*, Palisade Corporation, New York.

Pandey, S. 1990, 'Risk-efficient irrigation strategies for wheat', *Agricultural Economics*, vol. 4, pp. 59–71.

Pannell, D.J., Malcolm, B. and Kingwell, R.S. 1995, 'Are we risking too much? Perspectives on risk in farm modeling and farm management', Paper presented to the 39th Annual Conference of the Australian Agricultural Economics Society, University of Western Australia, Perth, 14–16 February.

Pratt, J. 1964, 'Risk aversion in the small and the large', *Econometrica*, vol. 32, no. 1, pp. 122–36.

Rae, A.N. 1970, 'Capital budgeting intertemporal programming models, with particular reference to agriculture', *Australian Journal of Agricultural Economics*, vol. 14, no. 1, pp. 39–52.

Rae, A.N. 1971, 'An empirical application and evaluation of discrete stochastic programming in farm management', *American Journal of Agricultural Economics*, vol. 53, no. 4, pp. 625–38.

Rae, A.N. 1977, *Crop Management Economics*, Granada, London.

Raskin, R. and Cochran, M.J. 1986, *A User's Guide to the Generalised Stochastic Dominance Program for the IBM PC*, Department of Agricultural Economics and Rural Sociology, University of Arkansas, Fayetteville.

Savage, S.L. 1992, *What's Best! The ABC's of Optimisation*, Lindo Systems Inc., Chicago.

Schoemaker, P.J.H. 1982, 'The expected utility model: its variants, purposes, evidence and limitations', *Journal of Economic Literature*, vol. 20, June, pp. 529–63.

Wall, L., Marshall, G., Jones, R. and Darvall, D. 1994, *Economics of On-Farm Proposals: Berriquin Land and Water Management Plan*, a report to the Berriquin Community Working Group, NSW Agriculture, Yanco.