The Tactics of Dryland Farm Management given Variance in Climate and Prices

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A model of the dryland farming system in the eastern wheatbelt of Western Australia is briefly described. The model incorporates climatic and price risk and tactical manangement responses to the climatic risk. The nature and benefits of tactical decision making for risk averse management are presented and are shown to vary according to the degree of risk aversion and commodity price relativities. Some tactical decisions are shown to contribute importantly to farm profit, with the bulk of these contributions occurring in the best seasons, and also occasionally in the worst seasons.

Key words: dryland farming system, discrete stochastic programming model, tactics.

INTRODUCTION

Dryland farming systems which depend on the vagaries of climate are common in world agriculture. In Australia researchers have long been interested in climatic or season variation (eg Williams, Pittock et al) and its impact on dryland agriculture (Anderson). The effect of drought on agriculture and related industries has received particular attention (Duloy and Woodland, Lovett, Anderson and Hardaker, Chapman, Wonder and Howlett).

Season variation and price variation and their impact upon a farm system can be represented in various ways in mathematical programming models (Hazell and Norton). In this paper discrete stochastic programming (DSP) is used to represent season and price variation plus tactical decision-making in a dryland farming system. Since the first farm system application of DSP (Rae) only a handful of other farm system applications have been reported in the literature (Garoian et al, Lambert, Schroeder and Featherstone, Featherstone, Preckel and Baker). To my knowledge DSP is yet to be applied to a dryland farming system.

In DSP, season and price variance are approximated by discrete distributions of season and price. This can be a disadvantage insofar as adequate representation of season and price variance may demand consideration of many discrete states, resulting in large models that risk being opaque

(MacPherson and Bennett). An advantage of DSP, however, is that its sequencing of decisions is consistent with usual farm management practices along with its assumption that some decisions are made after some seasonal conditions are observed.

This feature of DSP farm models, representing major adjustments to a farm plan that a farmer may consider in each discrete season or price state, is one of their strengths. Such representation of tactical decisions is, at least at the whole-farm level, a somewhat neglected area of research by agricultural economists. In many farm models that allow for season and price variance, the common practice has been to ignore the potential for tactical adjustments of a farm strategy according to short term seasonal conditions. Further, as Mjelde et al. (1989) observed; "the role of time and the attendant possibility for the decision maker to gather information as the production horizon unfolds generally have not been depicted realistically" (p 1).

The failure of some farm models to represent season and price variance and appropriate tactical responses means that some management strategies are incorrectly identified as being optimal (Kingwell et al.,(in press)). Further, statistical estimation of production function parameters will usually result in biased and inconsistent estimates (Antle 1983, Antle and Hatchett).

Most farm studies of tactical decision making have employed partial models focusing on a single enterprise or input. For example, Nordblom et al and Mjelde et al have studied nitrogen input. Thorton and Dent, Stefanou et al and Antle (1988) have examined pesticide use. This paper departs from such previous studies by focusing on whole-farm effects. In this paper are estimated the whole-farm benefits associated with tactical decision making for risk averse farmers in a dryland farming region of Australia.

THE FARMING SYSTEM

The dryland farm system examined in this paper is that of the Merredin region of Western Australia, where most farms have a mix of crop and livestock enterprises. The region is an area of approximately 11,500 square kilometres with an average annual rainfall of 310 mm. Most rain falls from May to October, followed usually by a summer drought from December to March. Crops are sown in May to July and harvested in November to December. Average farm size in the region is approximately 2600 ha, most of which is cleared and arable. Farm operations are highly mechanised and most farms are owner-operated with not more than one other permanent labourer. Casual labour is hired for only a few months of the year to assist in main tasks such as seeding and harvesting of crops and shearing of sheep.

Crops include cereals (mainly wheat) and the legume crops, lupins and peas. Livestock consist almost entirely of sheep for wool and meat production. Lambing is in late autumn or early winter and shearing is in spring and autumn. Sheep are run on annual pastures during winter and on a combination of crop residues and dry annual pastures in summer. The pastures contain volunteer annual grasses and herbs, with annual legumes introduced in some situations. Crops and pastures are commonly grown in rotation and a recent trend is toward cereal/lupin rotations on sandy soils.

Soils are highly weathered and some are infertile, with wheat yields in the Merredin region averaging 1.1 t/ha. Soil type differences affect the selection and management of enterprises. Most farms possess a mix of soil types, each with different production parameters and management requirements. Seven broad soil classes can be recognised in the region: acidic sands, good sandplain soils, gravelly sands, duplex soils, medium-heavy soils, heavy non-friable soils and heavy friable soils.

THE FARM MODEL

In the late 1980's a team of Western Australian researchers (Kingwell et al, 1991) developed a dryland farm model called MUDAS (Model of an Uncertain Dryland Agricultural System). The model accounts for season and price uncertainty and farmers' risk attitudes and abilities to respond tactically to seasonal events. The main purpose of model development was to investigate whether or not inclusion of uncertainties and associated tactical responses necessarily provided information of more value to researchers and extension agents than that generated by simpler deterministic models.

MUDAS is a DSP model describing:

(i) season variation and its effects on production outcomes, returns and some product and input prices;

(ii) a farmer's decision-making flexibility. Although there is uncertainty, as a season unfolds there are some decisions farmers can make, which favourably alter the impact of that season on production and profits. This flexibility is normally limited by previous decisions and so, in practice, flexibility in decision-making is the modification or adjustment of farm plans.

(iii) product price variance and farmers' aversion to risk.

As a DSP model, MUDAS can incorporate various objective functions associated with risk-neutral or risk-averse farm management. Optimization is through selection of an optimal set of farm activities which, for risk averse management, enable the maximization of expected utility. These activities draw upon the farm's limited resources of soil areas, finances, machinery and labour. Included in the set of optimal activities are decisions about rotation selection on each soil class, adjustments to crop and pasture areas in certain seasons, livestock numbers and flock composition, livestock feeding and husbandry in each type of season, machinery and labour use in each season, agistment, livestock selling and grain storage, fertiliser and stocking rate decisions and working capital requirements. The activity options available to the farm manager are represented as column entries in a data matrix. The resource and logical limits to activity selection are represented as row entries in the same matrix.

The tactical or adjustment options in MUDAS relate to a particular season or set of seasons. The adjustment options represent a second stage in the decision sequence. In this second stage, some information is known about the season and the farmer may choose to make adjustments to farm plans to increase profit or utility in the light of this information.

In MUDAS there are over 52,000 coefficients and many of these are derived or specified in spreadsheets that describe the data and assumptions of the model. The data input file for MUDAS is over 2 MB and there are over 12 MB of spreadsheets. The model comprises 2265 activities and 1464 constraints. The solving algorithm used by MUDAS is AESOP, a linear version of MINOS for microcomputers. File management is accomplished using MARG (Pannell), a programme to facilitate the running of mathematical programming models such as MUDAS.

Season types

In MUDAS season variation is approximated by nine discrete seasons. The season types and their classification characteristics are given in table 1. A full description of the data and methods used to categorise the seasons is given in Kingwell et al (1991).

Strategic activities

The strategic section of MUDAS includes rotational land use and sheep management activities. In addition, there are strategic activities setting cropping machinery investment, grain storage capacity and the initial level of grain stored.

Activity coefficients are unique to each season. These coefficients include estimates of pasture growth in each type of season, soil class and rotation phase; wheat yield responses to applied phosphate and nitrogen for each season, soil class and rotation phase; and yield estimates for other crops, such as lupins and peas, according to season, soil class and rotation phase.

Tactical activities

The tactical or adjustment options that the farm manager may consider within a season are a major component of MUDAS. Given some information about the start of a season and probabilities of associated finishes to seasons, a farm manager can deviate from his overall farm strategy by pursuing some within-season tactical options. For example, part of a farm strategy may be to maintain continuous pasture on a particular soil class. However, in seasons highly favourable for cropping, a farm manager may choose to crop all or part of that soil class which would ordinarily be in pasture.

Some adjustment options have an impact in the following year. Representation of these adjustment options requires accounting for both their initial year and subsequent year effects. Initial year effects are the changes in inputs, costs and production that occur in the year of adjustment. Thus replacing pasture by wheat would mean accounting for the net change in inputs, costs and production of having one extra hectare of wheat and one less hectare of pasture than specified in the rotation.

Subsequent effects of adjustments reflect the fact that one year's deviation from a rotation may have effects in subsequent years on the soil fertility, weed burden and pasture availability. For example, in a wheat/pasture rotation, replacing one hectare of pasture with wheat may mean in subsequent years less pasture production, yet lower crop herbicide costs than assumed in the steady state wheat/pasture rotation.

The tactical or adjustment options represented in MUDAS arose from discussion with a small group of eastern wheatbelt farmers and from discussions with advisers and researchers at the Merredin Dryland Research Institute and at South Perth. Land use area adjustment, machinery and labour adjustments, sheep liveweight deviations and sheep agistment are tactical responses within a season, as are pasture and stubble management, lupin feeding and crop fertilization. All adjustment activities are either specific to one season type or specific to a combination of season types which cannot be distinguished at the time a decision is made.

The main areas of tactical decision-making included in MUDAS are as follows:

Crop and pasture areas

A major adjustment option for many farmers is to alter the area of crop or pasture, particularly on heavy soils, depending on seasonal conditions. In the MUDAS model the adjustment options for changing crop and pasture areas are restricted to the SI, S5, S6 and S7 classes of soil (see table 2) and involve all types of season except seasons 5 and 7 (see table 3).

The difficulty of representing the initial and subsequent year effects of altering crop and pasture areas is compounded by the fact that such adjustment activities are specific tc the nature and phase of a rotation. That is, it is not only different to replace pasture with wheat in a pasture/pasture/wheat rotation versus a wheat/wheat/wheat/pasture rotation, but there is also a difference in replacing the first rather than the second year of pasture.

Each of the adjustment options in table 3, along with their production and cost ramifications within a season and across seasons, are described in spreadsheet files. Data from these files are subsequently incorporated in MUDAS. Because the sequence of season types in subsequent years is unknown, effects in subsequent years are spread across all seasons and weighted according to the probability of occurrence of the season in which the adjustment occurs.[1]

Pasture and stubble deferment

Besides tactical decisions about crop and pasture areas, farmers also make tactical decisions about how much pasture and stubble sheep should graze now and how much should be deferred for future use. Since the amount of stubble and pasture grown in each season is different, the best decisions on use and deferment of feed could vary from season to season. In the case of stubble deferment, season to season differences in stubble quantity are observable as soon as the stubble is available. For this reason, separate deferment activities are represented for each season type. In the case of pasture deferment, differences in pasture production between some seasons occasionally cannot be distinguished at the time of deciding about pasture deferment, so separate deferment activities are not represented for all season types.

Crop machinery and labour

Another facet of tactical decision-making involves the use of crop machinery and labour. Although investment in seeding and harvesting machinery is assumed fixed across all seasons, its utilisation, combined with the hire of labour, is seasonally dependent. By altering hours worked per day and by hiring or not hiring additional labour, farmers tactically respond to seasons. Such tactics are included in MUDAS. The direct costs of these tactical decisions on labour costs, machinery use depreciation, repairs and maintenance of machinery and yield losses associated with late sowing, are all included in MUDAS.

Livestock management

If MUDAS did not consider adjustments to livestock management, carrying capacity would be constrained to the feed available in the poorest season. Ignoring the flexibility of farmers' management of their sheep would lead to MUDAS selecting very conservative stocking rates and downgrading the profitability of the sheep enterprise.

In reality, farmers respond to seasonal conditions by changing their sheep management. Some of the changes are adjustment of the amount of grain fed to sheep, agistment, purchase or sale of sheep and allowing sheep liveweight to deviate from the pattern of average seasons.

In MUDAS the livestock management adjustments considered (table 4) are options to feed grain to sheep each month in each season, agistment of dry ewes, wethers and hoggets and deviations from a liveweight pattern which would occur in an average season.

Crop fertiliser adjustments

One important tactical decision in crop management is the amount of nitrogenous fertiliser to be applied. In MUDAS, selection of nitrogen and phosphate rates of application is exogenous to the model. The particular rates selected are derived from information on:

. season condition prior to and at crop sowing;

. probabilities of various finishing conditions - given start conditions;

. soil class and the effects of rotation on soil nitrogen status.

The optimal rates of applied nitrogen and phosphate for crops in various rotations, across soils and seasons, are determined in a series of spreadsheets. The data required by these spreadsheets come from three models: the NP-Decide model (Burgess); a water balance crop growth simulation model (Perry) and MIDAS (Morrison et al, Kingwell and Pannell). All these data enable description of crop yield response to different rates of applied nitrogen and phosphate within rotations, soils and seasons.

Financial and risk activities

These activities include the sale and purchase of commodities and inputs, cash flow and risk activities. They represent the financial consequences of the strategic and tactical activities selected.

Product price variance

An examination of price variances of a range of inputs and farm products revealed that, in real terms over the last decade, farmers have faced little price variance for their major inputs of repairs and maintenance, machinery, herbicides and fertilisers. Fuel is the exception. For farmers' main commodities such as wheat, live sheep, wool and lupins, real price variance has been marked over the last decade. Hence, because the main source of price risk for farmers was the variable prices they received for their major commodities, only product price variance was included in MUDAS.

MUDAS is structured with cash flow rows that represent commodity prices in any group of five years between 1981-82 and 1990-91. Farm-gate prices expressed in 1989-90 dollar terms are recorded for wheat, lupins, over 20 sheep classes, barley, oats, peas and three wool classes. Some lupin prices and sale prices for some sheep classes needed to be adjusted for the effects of some seasons. It is widely acknowledged that in seasons in which sheep feed is very scarce, farmer demand for lupins increases and farmers quit more sheep. These decisions by farmers cause in these seasons an increase in lupin prices and a lowering of sheep prices among cast-for-age categories in particular. These effects are included in MUDAS and represent a modification of historical prices only in the few seasons in which sheep feed would be very scarce.

Risk aversion

The representation of risk aversion in MUDAS is by a method developed by Patten et al (1988) and derived from work by Lambert and McCarl (1985). Lambert and McCarl applied non-linear programming techniques to maximise directly expected utility. Patten et al followed the same approach as Lambert and McCarl except that they applied linear rather than non-linear programming techniques. The treatment of risk by Patten et al involved the linear segmentation of the utility function and, unlike the Lambert and McCarl method, required the utility function to be concave. This last restriction on the utility function was tolerable since it implied risk aversion, the risk attitude most commonly observed among farmers (e.g. Bond and Wonder, Bardsley and Harris).

In MUDAS four linear segments are used to define a constant absolute risk aversion utility function in each season, with the length of each segment being conditional on the type of season and associated activity returns.[2] This method of incorporating risk easily accommodates different degrees of risk aversion.

RESULTS AND DISCUSSION

The benefits of tactical decision making are illustrated by contrasting model solutions that include tactical options against those that exclude certain main tactical options. The excluded tactical options are within-season adjustment of crop and pasture areas, agistment of livestock, altering livestock condition, adjustments in the hire of crop labour and adjustments to daily working rates of cropping machinery.

"With" Tactical Options

Results for risk averse management, assuming all tactical options are available, are presented in table 5. The results are for 3 levels of risk aversion and two different commodity price scenarios. The first price scenario assumes the commodity prices from 1981-2 to 1985-6. This was a period characterized by relatively high grain prices and low stable wool prices. The second price scenario is from 1986-7 to 1990-1, a period characterized by variable wool prices that were historically high relative to grain prices, and the price relativity between wheat and lupins switched such that often the price for lupins exceeded that of wheat (Fig.1).

(Figure 1 about here)

For risk averse management 3 levels of the Pratt-Arrow measure of absolute risk aversion are used, 0.000001, 0.000003 and 0.000005.

The results in table 5 show that rotation selection on many soil classes is sensitive to the commodity price scenario. Contrasting rotation selection in price scenario 2 against that in price scenario 1 shows a switch of resources into lupin production on the sandy soils, particularly S2 and S4 soil classes (see table 2) and the introduction of additional areas of pasture on the soil classes S5, S6 and S7. In short, model solutions for price scenario 2 involve a greater commitment of farm resources to lupin and wool production, at the expense of wheat production.

The greater area devoted to lupins in price scenario 2 can be explained firstly by the higher lupin prices relative to wheat in the period 1986-7 to 1990-1, secondly by the sandy soils being agronomically suited to lupin growing and lastly by an increased demand for lupin grain for hand-feeding to sheep. The increase in sheep numbers, wool production and pasture area in price scenario 2 is due to the expected wool and sheep prices being higher in price scenario 2 and expected lupin and cereal prices being lower. Associated with the increase in stock numbers and stocking rate are increased demand for lupin grain to hand-feed to sheep during the late autumn and early winter period of feed scarcity, increased purchases of lupins and, in most cases, more grain storage. In price scenario 2 the area of pasture is greater on the clay soils S5, S6 and S7. Pasture production on these soils rather than the sandy soils is preferred because the opportunity cost of displacing cereals and lupins with pasture on the sandy soils is substantial.

Within each price scenario the effect on farm model solutions of increasingly risk averse management is an increased emphasis on wool production. A consistent finding for each price scenario is that as risk aversion increases then so does the area of pasture, livestock numbers, wool production, stocking rate and lupin feeding per livestock unit. The finding that stocking rate increases with risk aversion is an unexpected result. McArthur and Dillon (1971), for example, comment on "the general rule that the more averse a farmer is to risk, the lower should his stocking rate be." (p. 23) Investigating the reasons for the unexpected result reveals the important way livestock income can affect the distribution of farm profit across seasons.

Explaining further, a risk-averse decision maker will prefer to avoid the very low incomes of some seasons, even at expense of foregoing some income in the better seasons when farm incomes are very high. The low incomes are associated with low revenues from crops, particularly those grown on soil classes S5 and S6 in seasons 8 and 9. One means of bolstering incomes in these poorer seasons is to devote more resources to sheep production. By increasing the area of pasture, lengthening pasture phases of rotations[3], enlarging flock size, increasing both grain feeding and stocking rate, additional income is generated in the poorer seasons, mainly from wool sales. However, the additional income is at cost of foregone lupin sales, greater expenditure on grain storage and lower incomes in the better seasons when the profitability of cropping is greater. In these better seasons the support of a larger sheep flock either restricts opportunities to increase the area and profits from cropping and/or reduces profits from the sheep enterprise due to requirements for additional grain feeding, lupin storage and grain purchases. In short, pursuit of higher stocking rates generates additional income from wool and livestock sales in the poorer seasons but incurs profit reductions in the better seasons due to restrictions on profits from cropping or livestock enterprises as illustrated later in table 7.

Associated with the results in table 5 are a suite of tactical decisions that affect the expected values in table 5. These tactical decisions involve nitrogen fertilizer applications on rotation phases on each soil type in each season, within-season adjustments to crop and pasture areas, agistment of livestock, adjustments in the hire of crop labour, seasonal adjustments to grain purchases and grain feeding and adjustments to work rates of cropping machinery. For the sake of brevity only key tactical decisions selected in MUDAS at only two levels of risk aversion for each price scenario are given in table 6.

Results in table 6 show that in the seasons in which crop yields are relatively high - seasons 1,2,4 and 6 - areas of pasture are replaced by wheat on the clay soils. Conversely, in the seasons in which prospective wheat yields on clay soils are low, pastures substitute for wheat. Also in these poor seasons lupins on S4 soil are replaced by wheat; lupins being extremely low yielding on this soil class in such seasons. The degree of substitution between crops and pasture in a particular season mainly reflects their relative profitabilities in that season. The tactical decisions to alter crop and pasture areas causes wide variation across seasons in the percentage of arable area in crop as shown in table 7. At each level of risk aversion, the dryland farm management is characterized by flexibility in land allocated to crops and pasture.

In MUDAS sheep nutritional requirements in each type of season are met mainly by the pasture production in that season, supplemented by crop residues produced in that season plus additional grain-feeding in late autumn and early winter, if required. Lupin grain fed to sheep may come from grain purchases or grain stored on farm. There are many tactical decisions made about grain purchases and grain feeding as indicated in table 6. Even in seasons in which pasture and crop yields are likely to be high, grain feeding is still required in late autumn due to the twin influences of a reduction in feed supply caused by tactical reductions in the area of pasture and an increase in feed demand from pregnant or lactating ewes. The largest increases in grain purchases and grain feeding occur in season 9 in which crop yields and pasture production are very low, in spite of an increase the area of pasture in this season. Overall, levels of grain feeding and grain purchases are greater with increasing risk aversion. These greater levels arise from the higher stocking rates and flock sizes selected by more risk averse management. The higher stocking rates depress pasture production and thereby increase the requirement for additional grain feeding.

Another feature of tactical decisions regarding livestock is the selection of winter agistment in some seasons. Although expensive, particularly in seasons when feed supply is poor, agistment offers the possibility of maintaining a larger sheep flock than might otherwise be possible. It reduces grazing pressure on winter pasture and reduces the need for grain feeding in early winter. In price scenario 2 greater emphasis is given to agistment, in part reflecting the greater profitability of the sheep enterprise such that agistment can be afforded. Rather than agisting some sheep in only the worst season, sheep are agisted in seasons 5, 7 and 8. At the time the agistment decision is made it is not possible to discern whether the particular season is season 5, 7 or 8. Hence, the same number of sheep are agisted in each of these seasons, although the ramifications of the agistment decision differ for each of the seasons.

A final feature of the livestock tactical decisions listed in table 6 is altering the bodyweight condition of sheep. Although not always a conscious act, farmers nonetheless often allow their animals to increase in weight and condition in the better seasons and to lose weight and condition in the poorer seasons. This style of management is an option in MUDAS and is selected as part of risk averse management.

Results in table 7 show that as risk aversion increases so farm profit in the better or more profitable seasons such as seasons 1,2,4 and 6 decreases. However, in the poor or unprofitable seasons, such as seasons 3,8 and 9, losses diminish with increasing risk aversion. Expected profit diminishes with increasing risk aversion indicating that the farm plans with the higher stocking rates have less expected profit. Stocking rates increase in each season, but particularly in season 9, as risk aversion increases. The percentage of the farm in crop is noticeably reduced in the better seasons 1,2,4 and 6 as risk aversion increases.

The results in table 7 indicate that at each level of risk aversion there are many tactical changes within seasons to crop areas, wheat sales and stocking rates, although their degree of change as indicated by the coefficients of variation lessens with increasing risk aversion as does farm profit. Lupin sales diminish with increasing risk aversion mainly due to requirements for the hand-feeding of a larger sheep flock.

"Without" Tactical Options

At each level of risk aversion and for each price scenario, the following tactical options are excluded individually - firstly, tactical changes to crop and pasture areas; secondly, agistment of livestock; thirdly, allowing sheep liveweight patterns to deviate from expected season patterns, and finally, adjusting daily working rates of cropping machinery and the amount of hired crop labour. The mai expected effects of removing each option are given in Table 8.

Results in table 8 indicate that the options to agist sheep off-farm and allow sheep liveweight patterns to deviate from patterns in an expected season, contribute little to expected farm profit and land use. The certainty equivalent values of solutions that exclude these options are only slightly less than the certainty equivalent values of solutions that include these options.

By contrast, the tactical options to alter crop and pasture areas within seasons and alter cropping labour and the daily work rates of cropping machinery, contribute importantly to expected farm profit and affect land use. In price scenario 1, the certainty equivalents of farm plans that exclude the option to alter crop and pasture areas within seasons are around 10 per cent less than the certainty equivalents of farm plans that include all tactical options. In price scenario 2, excluding the same option reduces the certainty equivalents of farm plans by 11 to 16 per cent. Further, in price scenario 2, the effect on land use of excluding the option to alter within seasons crop and pasture areas is for pasture areas and sheep numbers to be greater. In price scenario 1, however, there is no clear trend in the land use differences between the *with* and *without* option cases. Nonetheless, in both price scenarios, the effect of increasing risk aversion in the *with* and *without* option cases is an increase in the area of pasture and sheep numbers. Also, the greater the degree of risk aversion the less is the contribution of this option to the certainty equivalent of model solutions that include all options.

In price scenarios 1 and 2, excluding the option to alter cropping labour and daily work rates of cropping machinery reduces the certainty equivalents of farm plans by around 8 and 6 per cent respectively. Given that the profitability of cropping versus sheep and wool production is higher in price scenario 1 relative to price scenario 2, it follows that the option to adjust cropping labour and machinery work rates provides greater returns in price scenario 1. Removing the option to adjust cropping labour and machinery work rates reduces the relative profitability of cropping and therefore it is not surprising that farm plans that exclude this option are characterised by smaller expected areas of crop. For example, given price scenario 1 and a Pratt-Arrow coefficient of 0.000001, the expected areas of crop for the *with* and *without* options to adjust cropping labour and machinery work rates are 1652 hectares and 1568 hectares respectively.

Consistent with the results for crop and pasture area adjustments, the greater the degree of risk aversion when the crop labour and machinery option is excluded, the less is the contribution of this option to the certainty equivalent of model solutions that include all options. Also sheep numbers and the area of pasture both increase with increasing risk aversion, in the *with* and *without* option for crop labour and machinery work rate adjustment.

In terms of certainty equivalents, the benefits of tactical options, particularly those arising from changes to crop and pasture areas, crop labour and machinery use, decrease with increasing risk aversion. For example, the certainty equivalent of the farm plan given price scenario 1, a Pratt-Arrow coefficient of 0.000001 and no crop or pasture area adjustment, is $15445 less than the certainty equivalent of the farm plan given the same conditions except all adjustment options are available. However, a similar comparison based on a Pratt-Arrow coefficient of 0.000005 produces a $10986 difference in certainty equivalents. However, expressed as percentages of the certainty equivalents of model solutions that include all options, such differences are of similar magnitude.

Results in table 8 highlight the profitability of the options to adjust crop and pasture areas and alter use of crop machinery and labour. The profits of these options are further examined by calculating, for each season, the difference in contributions to expected profit made *with* and *without* these tactical options. Table 9 lists these differences in contributions to expected profit for two price scenarios and two levels of risk aversion. A consistent result in table 9 is that, for either price scenario or level of risk aversion, the main source of additional profit associated with the two tactical options stems from tactical decisions in season 1. In season 1 summer rains provide stored soil moisture, crop preparation and pasture growth begin very early and crop and pasture yields are very high. These conditions allow sheep numbers to be retained on a smaller area of pasture and for the area of crops to increase. Such adjustments in crop and pasture areas in season 1 are highly profitable. Also profitable in season 1, but to a lesser extent, are changes to crop labour and machinery that allow more area to be planted more quickly to crops, thereby avoiding yield losses associated with sowing crops late. The fact that season 1 has the greatest frequency (p=0.17) of occurrence among the nine types of season also is part of the reason why these tactical options contribute importantly to expected farm profit.

Other seasons in which the tactical options also consistently contribute to improvement in expected farm profit, are seasons 2, 6 and 4, in order of relative magnitude. These are seasons in which crop and pasture yields are relatively high, enabling profits to increase by reducing the area of pasture, increasing the area of crop and increasing the labour and machinery work rates for crop establishment.

The option to alter crop and pasture areas within a season, particularly in price scenario 1, enables farm profits to increase in seasons 8 and 9. In these seasons crop yields on clay soils are very low (<700 kg/ha) and pasture growth is poor. In price scenario 1 commodity price relativities favour crop production, resulting in most of the area of clay soils being committed to cropping. However, in seasons 8 and 9 it becomes profitable to reduce the area of crop on the clay soils and thereby reduce income losses from poor crop yields. Avoiding such income losses is particularly important to a risk averse decision maker.

At the higher level of risk aversion (Pratt-Arrow coefficient = 0.000005), the option to alter crop machinery work rates and crop labour, also enables increased contributions (or less reductions) to expected farm profit in seasons 8 and 9. By quickly planting late-sown crops, avoiding further yield losses due to sowing delays and by employing less harvest labour, profits in seasons 8 and 9 are raised.

The findings that the contribution to expected farm profit of these tactical options occurs mainly in a few season types suggests that any research that assists in the early identification of these seasons is likely to be very valuable to farmers. Further, any research that facilitates the important tactical decisions of crop areas, crop machinery and crop labour use, may also be valuable to farmers.

CONCLUSIONS

A model of a dryland farming system is used to examine the nature and importance of tactical decision-making for a risk averse decision maker facing climate and price uncertainty. Results show that at each level of risk aversion, many tactical options are selected. Within many seasons there are changes to crop areas, grain feeding, stocking rates, pasture areas, agistment, the hire of crop labour, intensity of use of cropping machinery and management of livestock condition. The impact of these tactical changes on the distribution of farm profit across seasons, as measured by coefficients of variation, lessens with increasing risk aversion. Risk averse decision makers are shown to adopt strategies and tactics that generate more income in the poorer seasons at the expense of foregoing some income in the better seasons. The more risk averse the decision maker is, the more pronounced are these changes in incomes across these seasons and the less is the variance in farm profit.

In investigating the value of four areas of tactical decision making, results show important contributions to expected profit in two areas. The two areas are tactical options to alter crop and pasture areas within particular seasons and options to alter crop machinery work rates and use of cropping labour in particular seasons. Exclusion from farm plans of the option to adjust crop and pasture areas reduced the certainty equivalent of farm plans by 10 to 16 per cent. Excluding the option to alter labour and machinery work rates, reduced certainty equivalents by 6 to 8 per cent. The other two areas of tactical decision making - agisting sheep off-farm and allowing sheep liveweight patterns to deviate from an expected season pattern - barely lessened the certainty equivalents of farm plans.

The tactical decisions that contribute importantly to farm plan certainty equivalents, do so mainly in the very best seasons and occasionally also in the worst seasons. Their contributions particularly affect crop income and expenditure. In the very best seasons large increases in income are generated firstly, by increasing crop areas and secondly, by greater utilization of crop machinery and labour. In the worst seasons, reducing crop areas on the clay soils and altering machinery work rates and labour use, enables losses associated with cropping to be reduced, thereby bolstering farm income.

Overall, results show that risk averse dryland farm management is characterized by profitable dependence on tactical decision making. A few key areas of tactical decision making are highlighted, with an inference that research which facilitates tactical decision making in these areas could be potentially profitable research.

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1 See Kingwell et al (1991) for more explanation.

2 DSP is not limited to utility functions possessing constant absolute risk aversion (Schroeder and Featherstone).

3 Footnotes to table 5 identify the nature of pasture areas. Rotations dominated by pasture support higher stocking rates than those that are crop dominant.

Table I: Season types in MUDAS

Season	Opening rains	Summer rain index	Earlier sowing of lupins	Spring rainfall	Season proba-bility	Typical wheat yield (t/ha)[b]
I	early	high	n.a.	either	0.I7	I.96
2	early	low	n.a.	high	0.I2	I.27
3	early	low	n.a.	low	0.08	0.64
4	mid	high	yes	either	0.05	I.60
5	mid	low	yes	either	0.I2	0.8I
6	mid	high	no	either	0.I3	I.28
7	mid	low	no	either	0.09	0.77
8	late	either[a]	yes	either	0.I4	0.6I
9	late	either[a]	no	either	0.I0	0.57
				expected yield:		I.09

a Most of the years in this season type had low summer rain indices
n.a. Not applicable in seasons with early opening rains
b Based on Perry (I990) yield simulations for Merredin heavy soil.

Table 2: Soil classes in MUDAS

Soil class	Description	pH Range	Area (ha)
S1 (Acid sands)	Yellow, loamy or gravelly sands. Native vegetation is wodgil with sheoak and banksia on deep white sands.	< 5.5	460
S2 (Sandplain)	Deep, yellow-brown loamy sands. Native vegetation is grevillea and tamma.	5.5-6.0	460
S3 (Gravelly sands)	Yellow-brown gravelly sands and sandy gravels. Native vegetation is tamma.	5.5-6.0	230
S4 (Duplex)	Grey, sandy loams, loamy sands, gravelly sands and sand over white clay with yellow or red mottles. Native vegetation is mallee.	5.5-6.5	230
S5 (Medium heavy)	Red-brown, sandy loam over clay sub-soil. Native vegetation is salmon gum and tall mallee.	6.0-7.0	345
S6 (Heavy non-friable)	Dark red-brown, sandy clay loams. Native vegetation is gimlet, morrel and salmon gums.	> 6.5	460
S7 (Heavy friable)	Previous S6 soil treated with gypsum.	> 6.5	II5

Table 3: Adjustment options for altering crop or pasture areas

Option	Soil class	Season
Increase the area of pasture by replacing wheat	SI,S5,S6,S7	8,9
Increase the area of wheat by replacing pasture	SI,S5,S6,S7	I,2 and 3,4,6
Decrease the area of lupins by replacing with wheat	SI,S4	8,9

Table 4: Livestock management adjustments in MUDAS

Adjustment	Period	Season
Feed out lupins	Each month	1 to 9
Agist dry ewes, wethers and hoggets	Jun to Aug and/or Sep to May	3,5,7,8,9
Deviate from standard liveweight pattern:	The period of weight gain or loss depends on the particular season	
– relative weight gains		1,2,6,3,4
– relative weight losses		7,8,9

Table 5: Key management decisions in MUDAS at three levels of risk aversion given two price scenarios: with tactical options

Management decision	Pratt-Arrow coefficient $1x10^{-6}$	$3x10^{-6}$	$5x10^{-6}$
Price Scenario 1[a]			
profit ($)	169378	166726	165962
crop area (ha)	1652	1640	1624
pasture area (ha)	648	660	676
sheep numbers (dse)	1164	1236	1337
wool sold (kg)	5410	5741	6194
wheat area (ha)	1499	1439	1335
lupin area (ha)	153	234	288
wheat sold (tonnes)	1678	1568	1535
lupin sold (tonnes)	123	211	228
lupin storage (tonnes)	39	16	16
lupin bought (tonnes)	3	8	3
stocking rate (dse/ha pasture)[b]	1.76	1.83	1.94
lupin fed per dse (kg/dse)	12.4	12.8	14.3
rotations on soil class			
S1	PPPP	PPPP	PPPP
S2	WWL	WWWW & WWL	WWL
S3	WWWW	WWL	WWL

S4	WWWW	WWL	WWL
S5	WWWW	WWWW	WWWW
S6[c]	PW & PWW	PW & PWW	PW & PWW
S7	WWWW	WWWW	WWWW
Price Scenario 2			
profit ($)	83520	81459	79555
crop area (ha)	1440	1415	1354
pasture area (ha)	860	885	946
sheep numbers (dse)	1818	2271	2581
wool sold (kg)	8452	10274	12275
wheat area (ha)	1075	1054	1052
lupin area (ha)	365	361	302
wheat sold (tonnes)	1298	1246	1231
lupin sold (tonnes)	286	278	228
lupin storage (tonnes)	28	33	46
lupin bought (tonnes)	11	18	22
stocking rate (dse/ha pasture)	2.07	2.37	2.57
lupin fed per dse (kg/dse)	13.9	15.6	18.1
rotations on soil class			
S1	PPPP	PPPP	PPPP
S2[d]	WL	WL & WWL	WL & WWL
S3	WWL	WWL	WWL
S4	WWL	WWL	WWL
S5[e]	PWWWW & PW	PWWWWW & PPW	PWWWWW
S6[f]	PPW & PWW	PPPW	PPPPPW

S79 PPPPW & WWWW PPPP & WWWW PPPPW & WWWW

Note: All values in the table are expected values.

P = Pasture, W = Wheat, L = Lupin

a Price variance in scenarios 1 and 2 is based on the periods 1981-2 to 1985-6 and 1986-7 to 1990-1 respectively.

b Based on the expected number of sheep grazing winter pastures. Note agisted sheep are not included in this measure of stocking rate.

c The area allocated to these rotations is 231, 229, 266, 194, 315 and 145 hectares respectively. In these same rotations the expected pasture area is 52, 29, 54, 29, 55 and 29 per cent respectively.

d The area allocated to these rotations is 460, 438, 22, 82 and 378 hectares respectively.

e The area allocated to these rotations is 259, 86, 11, 334 and 345 hectares respectively. In these same rotations the expected pasture area is 20, 48, 62, 16 and 15 per cent respectively.

f The area allocated to these rotations is 338, 112, 460 and 460 hectares respectively. In these same rotations the expected pasture area is 64, 29, 73 and 85 per cent respectively.

g The area allocated to these rotations is 69, 46, 30, 85, 53 and 62 hectares respectively. In these same rotations the expected pasture area is 80, 0, 100, 0, 80 and 0 per cent respectively.

Table 6: Key tactical management decisions in MUDAS at two levels of risk aversion for two price scenarios

Price scenario	Season	Tactical decision
Pratt-Arrow coeff. = 1x10^{-6}		
1	1	On S6 soil replace 288 ha of pasture with wheat.
	2&3	On S6 soil replace 288 ha of pasture with wheat.
	4	On S6 soil replace 235 ha of pasture with wheat.
	6	On S6 soil replace 180 ha of pasture with wheat.
	8	On S6 soil replace 171 ha of wheat with pasture.
	9	On S6 soil replace 171 ha of wheat with pasture.
	9	Agist 324 dse from June to August.
	1	Feed 6 tonne of lupins.
	2	Feed 15 tonne of lupins.
	3	Buy 34 tonne of lupins, feed 34 tonne of lupins.
	4	Feed 11 tonne of lupins.
	5	Feed 5 tonne of lupins.
	6	Feed 6 tonne of lupins.
	7	Feed 5 tonne of lupins.
	8	Feed 15 tonne of lupins.
	9	Buy 7 tonne of lupins, feed 46 tonne of lupins.
	1,4,6	Allow sheep to gain body condition.
	8,9	Allow sheep to lose body condition.
2	1	On S6 soil replace 354 ha of pasture with wheat.

1	On S5 soil replace 134 ha of pasture with wheat.
2&3	On S7 soil replace 69 ha of pasture with wheat.
2&3	On S6 soil replace 205 ha of pasture with wheat.
2&3	On S5 soil replace 151 ha of pasture with wheat.
4	On S6 soil replace 263 ha of pasture with wheat.
4	On S5 soil replace 151 ha of pasture with wheat.
6	On S6 soil replace 185 ha of pasture with wheat.
6	On S5 soil replace 151 ha of pasture with wheat.
8	On S6 soil replace 93 ha of wheat with pasture.
8	On S5 soil replace 17 ha of wheat with pasture.
3	On S4 soil replace 115 ha of lupin with wheat.
9	On S6 soil replace 93 ha of wheat with pasture.
9	On S5 soil replace 195 ha of wheat with pasture.
9	On S4 soil replace 115 ha of lupin with wheat.
9	Agist 506 dse from June to August.
1	Buy and feed 13 tonne of lupins.
2	Buy 2 tonne of lupins, feed 16 tonne.
3	Buy 28 tonne of lupins, feed 43 tonne.
4	Buy 12 tonne of lupins, feed 25 tonne.
5	Buy 4 tonne of lupins, feed 24 tonne.
6	Feed 10 tonne of lupins.
7	Feed 10 tonne of lupins.
8	Feed 28 tonne of lupins.
9	Buy 48 tonne of lupins, feed 76 tonne.

	1,4,6	Allow sheep to gain body condition.
	8,9	Allow sheep to lose body condition.

Pratt-Arrow coeff. = $5x10^{-6}$

1	1	On S6 soil replace 351 ha of pasture with wheat.
	2&3	On S6 soil replace 313 ha of pasture with wheat.
	4	On S6 soil replace 261 ha of pasture with wheat.
	6	On S6 soil replace 196 ha of pasture with wheat.
	8	On S6 soil replace 108 ha of wheat with pasture.
	9	On S6 soil replace 108 ha of wheat with pasture.
	9	Agist 371 dse from June to August.
	1	Buy 5 tonne of lupins, feed 11 tonne.
	2	Buy 17 tonne of lupins, feed 24 tonne.
	3	Buy 27 tonne of lupins, feed 38 tonne.
	4	Buy 13 tonne of lupins, feed 20 tonne.
	5	Feed 7 tonne of lupins.
	6	Buy 1 tonne of lupins, feed 7 tonne.
	7	Feed 6 tonne of lupins.
	8	Buy 3 tonne of lupins, feed 19 tonne.
	9	Buy 37 tonne of lupins, feed 53 tonne.
	1,2,4,6	Allow sheep to gain body condition.
	8,9	Allow sheep to lose body condition.
2	1	On S6 soil replace 211 ha of pasture with wheat.
	1	On S5 soil replace 86 ha of pasture with wheat.
	2&3	On S7 soil replace 53 ha of pasture with wheat.

2&3	On S6 soil replace 81 ha of pasture with wheat.
2&3	On S5 soil replace 86 ha of pasture with wheat.
4	On S6 soil replace 162 ha of pasture with wheat.
4	On S5 soil replace 86 ha of pasture with wheat.
6	On S6 soil replace 60 ha of pasture with wheat.
6	On S5 soil replace 86 ha of pasture with wheat.
8	On S5 soil replace 29 ha of wheat with pasture.
8	On S4 soil replace 77 ha of lupin with wheat.
9	On S5 soil replace 86 ha of wheat with pasture.
9	On S4 soil replace 77 ha of lupin with wheat.
5,7&8	Agist 736 dse from June to August.
9	Agist 736 dse from June to August.
1	Buy 23 tonne of lupins, feed 23 tonne.
2	Feed 28 tonne of lupins.
3	Buy 29 tonne of lupins, feed 57 tonne.
4	Buy 9 tonne of lupins, feed 35 tonne.
5	Buy 12 tonne of lupins, feed 53 tonne.
6	Buy 25 tonne of lupins, feed 51 tonne.
7	Feed 28 tonne of lupins.
8	Buy 48 tonne of lupins, feed 54 tonne.
9	Buy 70 tonne of lupins, feed 116 tonne.
1,2,4,6	Allow sheep to gain body condition.
8,9	Allow sheep to lose body condition.

Table 7: Key outcomes associated with tactical management decisions in MUDAS for two levels of risk aversion and two price periods

Season	profit ($)	stocking rate (dse/ha of pasture[a])	lupin sold (tonnes)	wheat sold (tonnes)	wool sold (kg)	crop area (% of arable area)
Pratt-Arrow coeff. = 1x10-6						
1	265360	3.26	433	2692	8565	76
2	164204	2.94	458	1679	8441	73
3	-8719	2.94	216	830	8441	73
4	185068	2.88	380	2087	8441	72
5	23992	1.75	333	673	8441	54
6	117470	2.57	265	1616	8634	69
7	3129	1.75	215	651	8441	54
8	-23183	1.55	141	528	8320	50
9	-50338	0.99	78	451	8260	42
Expected Values						
	83520	2.07	286	1298	8452	63
Coefficient of Variation (%)						
	148.0	38.4	43.0	58.1	1.3	18.9

Pratt-Arrow coeff. = 5x10^{-6}

1	236438	3.50	375	2402	12452	67
2	145736	3.17	377	1453	12272	64
3	-870	3.17	177	765	12272	64
4	172294	3.28	316	1913	12272	65
5	26671	1.82	249	737	12272	54
6	103728	2.92	202	1489	12552	60
7	15580	1.82	168	731	12272	54
8	-12646	1.77	94	605	12011	53
9	-29897	1.68	47	594	12000	50
Expected Values						
	79555	2.57	228	1231	12275	59
Coefficient of Variation (%)						
	138.0	28.3	48.3	50.2	1.4	9.9

Table 8: Key MUDAS results at three levels of risk aversion given two price scenarios: without tactical options

Missing tactical option	Result	Price Scenario 1 Pratt-Arrow coeff			Price Scenario 2 Pratt-Arrow coeff		
		$1x10^{-6}$	$3x10^{-6}$	$5x10^{-6}$	$1x10^{-6}$	$3x10^{-6}$	$5x10^{-6}$
none	profit ($'000)	169.4	166.7	166.0	83.5	81.5	79.6
	crop area (ha)	1652	1640	1624	1440	1415	1354
	pasture area (ha)	648	660	676	860	885	946
	sheep no. (dse)	1164	1236	1335	1818	2271	2581
	C.E. ($'000)	155.7	130.7	111.7	77.2	63.7	53.7
changes to pasture or crop areas	profit ($'000)	152.8	148.7	142.6	68.5	68.4	65.8
	crop area (ha)	1789	1660	1574	1380	1380	1333
	pasture area (ha)	511	640	726	920	920	967
	sheep no. (dse)	943	1243	1518	2566	2567	2801
	C.E. ($'000)[a]	140.2	117.1	100.7	65.2	55.5	47.9
agistment	profit ($'000)	169.3	166.6	165.8	83.4	82.4	82.2
	crop area (ha)	1652	1640	1623	1441	1424	1416
	pasture area (ha)	648	660	677	859	876	884
	sheep no. (dse)	1172	1245	1346	1883	2007	2002
	C.E. ($'000)[a]	155.5	130.5	111.5	77.1	63.4	52.5
livestock condition	profit ($'000)	168.0	166.6	166.8	83.3	81.5	79.2
	crop area (ha)	1652	1641	1623	1443	1421	1354

	pasture area (ha)	648	659	677	857	879	946
	sheep no. (dse)	1166	1233	1337	1798	2089	2636
	C.E. ($'000)[a]	155.4	130.4	111.4	76.9	63.4	53.2
changes to	profit ($'000)	154.9	153.0	152.3	77.9	76.2	75.6
cropping	crop area (ha)	1568	1565	1545	1419	1317	1302
labour &	pasture area (ha)	732	735	755	881	983	988
machinery	sheep no. (dse)	1568	1573	1688	2120	2622	2754
work rates	C.E. ($'000)[a]	143.2	120.5	103.0	72.2	59.8	50.11

[a] C.E. is the certainty equivalent

Note: All values in the table are expected values except for the certainty equivalent.

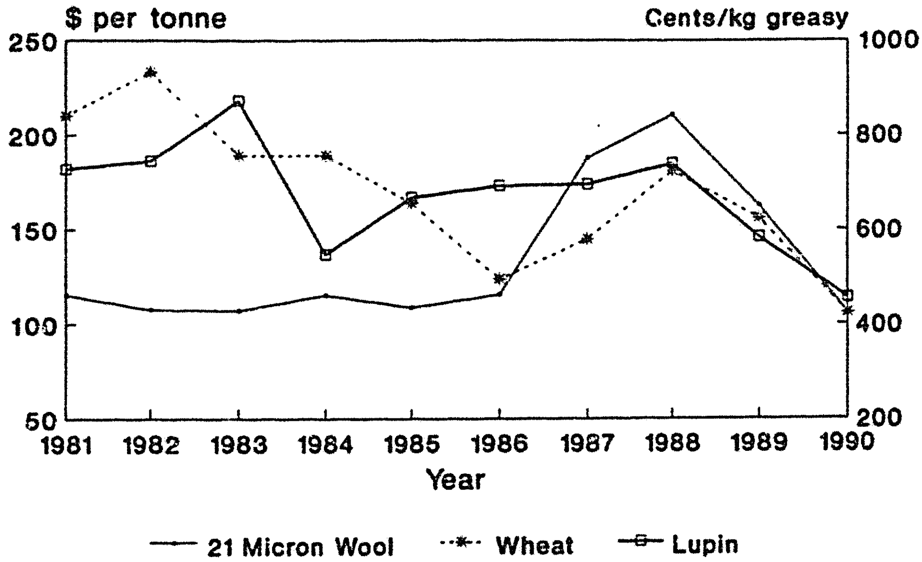
Table 9: Differences in season contributions to expected profit for two sorts of tactical decisions,

given two price scenarios and two levels of risk aversion

Season	Difference in season contributions to expected profit for including all tactical options versus excluding adjustment of:			
	crop & pasture area ($)		crop machinery work rates & crop labour ($)	
Price Scenario 1				
Pratt-Arrow coeff.	0.000001	0.000005	0.000001	0.000005
1	4848	13160	5935	6380
2	1411	5411	3068	3031
3	185	404	449	476
4	354	1377	777	854
5	-24	314	551	638
6	1734	1036	1486	1420
7	930	-153	-243	-165
8	2877	767	420	1477
9	3205	2135	-455	1471
Price Scenario 2				
Pratt-Arrow coeff.	0.000001	0.000005	0.000001	0.000005

1	12173	10403	2816	989
2	3863	3451	1147	599
3	-588	-818	179	-70
4	1513	1704	714	202
5	-1670	-1698	-464	186
6	2615	1419	1274	521
7	-1507	-884	-782	81
8	-432	-134	630	836
9	-941	269	115	622

Figure 1: Examples of on-farm commodity prices: 1981/2 to 1990/1



Prices are expressed as on-farm 1989/90 constant prices.