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CLIMATIC RISK AND THE VALUE OF INFORMATION

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Notwithstanding the high variance of world prices for most agricultural commodities (e.g. Hatch et al. 1980), climate is the major source of risk faced by dry land wheat/sheep farmers in Western Australia. These farmers place a high value on information about weather patterns, as indicated by the recent growth of commercial services providing them with long term weather predictions. Even without such predictions, however, dryland farmers have access to information about climatic events in the recent past. This information is valuable because it can be used to revise yield probability distributions of alternative enterprises being considered for the forthcoming growing season. Of course the information is partial; it allows revision of yield probability distributions but not perfect yield predictions. Even so, this limited information can improve farmers' decision making about enterprise selecting and management.

Antic (1983) observed that seasonal variation affects farmers' decision making in two ways:

- (a) risk averse farmers adopt long term farming strategies which reflect a preference for income stability as well as higher income. There is evidence that most Australian farmers are risk averse (Bond and Shand 1980; Bartolay and Harris 1981).
- (b) both risk averse and risk neutral farmers make tactical adjustments to their farming strategies in response to short term seasonal conditions. There are potentially two facets to the value of climatic information used to make these adjustments. They allow improvements in expected income for all farmers and they can reduce the cost of risk for farmers who are risk averse.

Although agricultural economists have invested much effort in studies of the longer term implications of seasonal variation for risk averse farmers, much less emphasis has been placed on shorter term (*i.e.*, within-season) tactical decisions. Hinde et al. (1989) observed that the role of this and the attendant possibility for the decision maker to gather information as the production horizon unfolds generally have not been depicted "realistically" (p. 1). Even in models which allow for seasonal variation and risk aversion, the common practice has been to ignore the potential for tactical adjustments to the farming strategy according to short term seasonal conditions.

This neglect of the role of climatic information may have serious consequences. Firstly it results in underestimation of the profitability of some strategies. For example, a strategy to continuously crop one soil type of the farm may be profitable in most seasons but very unprofitable in some poor seasons. If these poor seasons are at least partially predictable from climatic conditions prior to sowing, expected profits can be increased by choosing not to sow crops in those conditions. If tactical adjustments were not included in a model, the continuous crop strategy would be generalized by

the absence of an option to temporarily abandon the strategy in some seasons.

The second consequence of ignoring climatic information in economic models is that statistical estimation of production function parameters will usually result in biased and inconsistent estimates (Antic 1983; Antic and Hatchett 1988). Thus short term tactical adjustments to farm strategies are important for both descriptive and prescriptive studies of farmer behaviour (Hinde et al. 1989).

Analyses of tactical decision making by farmers have included studies of nitrogen inputs (Hordijk et al. 1985; Hinde et al. 1989) and pesticides (Thornton and Bent 1984; Antic 1984; Stepanco et al. 1984). Adjustments to nitrogen decisions in these studies depended on information about climatic, the pesticide studies included a range of information types but generally information from scouting to estimate pest densities. Most studies found that the information led to increases in expected profits or expected utility. All of these studies employed partial farm models focusing on a specific crop and a single type of farm input. We are not aware of any study which has used a whole-farm model to analyze the use of climatic information to adjust farm enterprise selection.

Our aim in this paper is to estimate the whole-farm benefits of climatic information used for tactical decision making by risk neutral farmers in western Australia. The types of tactical adjustment considered in the model include changes in enterprise selection, management practices and input levels but this study focuses on changes in enterprise area. In the following sections we briefly describe the farm system which is the subject of the analysis and present details of the discrete stochastic programming model used in the study. Results of individual annual runs and sensitivity analyses are presented and discussed before some brief concluding comments.

The Farm System

Agriculture in Western Australia is largely confined to the south-east corner of the state, an area of approximately 210,000 square kilometers. The dryland farm system modeled is based on Barred in Shire in the eastern Wheatbelt where almost all farms have a mix of crop and livestock enterprises. Annual rainfall in the region averages 316 mm, with most rain falling from May to October, followed 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 2500 hectares, most of which is cleared and arable. Farm operations are highly mechanized and most farms are owner operated with not more than one other permanent laborer. Casual labor is hired for only a few months of the year to assist in such tasks such as seedling, harvesting and shearing.

Crops include cereals (mainly wheat but also barley, oats and triticale) and the legume crop lupin. Livestock consist almost entirely of sheep for wool and meat production. Lambing is in late autumn or early spring 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 infertile, with wheat yields in the Warradigby Shire averaging 1.0 tonnes per hectare. Enterprise selection and management according to soil type is a key part of the farming system. All farms include a mix of soil types with different production potentials and management requirements. Seven broad soil classes can be recognized in the region: acidic sands, good sand plain soils, gravelly sands, duplex soils, medium-heavy soils, heavy non-irrigable soils and heavy friable soils. Further details of the soils are presented by Ghoshal and Penrell (1991).

The Discrete Stochastic Programming Model

MIDAS (Model of an Uncertain Dryland Agricultural System) is a DSS model using linear programming to analyse multi-stage stochastic problems in which the optimal activity in one period depends on events in past periods. Fod (1974, 1975) intended the model and applied it to a vegetable farm. After this's applications, there was a period with few agricultural applications of the technique (Lambert 1981) but recently it has been the subject of renewed interest from agricultural economists (e.g. Green and Bryman 1986; Lambert 1986; Lambert and McCullough 1988; McCullough et al. 1991).

MIDAS (Model of an Uncertain Dryland Agricultural System) is a DSS model developed by the Western Australian Department of Agriculture to describe a typical farm in the eastern wheatbelt of Western Australia. The following brief overview of the model can be supplemented by a more detailed description published by Kingwell et al. (1991).

In this study the assumed objective is maximization of expected net returns. Other goals relating to labour and soil conservation are represented explicitly as constraints. Net returns are calculated as gross cash receipts minus variable production costs, fixed production costs, living expenses and the opportunity costs of holding assets other than land.

The model handles dynamics as a timeless one-year loop, whereby parameters for a given year are based on the assumption that the same strategy will be adopted in previous years. Interval effects on technical parameters are thus dependent on the solution selected for the current year, so that the model finds an optimal "equilibrium" solution. This approach greatly reduces model size and facilitates much greater detail in the biological constraints and tactical adjustments represented while still capturing the essential interyear and interyear dynamics of the farm system. Within the year there are a number of nodes at which decisions must be made contingent on what has already occurred. There are 12 decision nodes for supplementary feeding of grain and for sheep live weight adjustments and two nodes for enterprise area and sheep adjustment decisions. The model includes approximately 1400 activities and 1200 constraints (a purely linear version of MIDAS) microcomputers using the ABBOP algorithm (a purely linear version of MIDAS) and MACS (Penrell 1990) for matrix generation and report writing.

A feature of MIDAS is its detailed representation of biological relationships and complex enterprise interdependences, both beneficial and adverse, that exist in the dryland farming system. For example, the model includes representation of:

- seven distinct soil classes, each with unique input-output relationships and numerous rotation options.

- the decreasing effect of cropping on subsequent pasture density and productivity,
- the supply of nitrogen by leguminous crops and pastures to subsequent cereal crops and the yield response to nitrogen of different crops in each soil class,
- the added wage burden to crops attributable to previous pasture,
- the various quantities and qualities of crop residues available for feeding sheep, and the dynamics of their deterioration,
- the use of lucerne and cereal grains as sheep feed to improvement pastures and crop residues,
- yield penalties associated with late planting of crops,
- the decreasing effect on pasture growth of decreases in stocking rate.

MIDAS is derived from MUDAS (Model of an Integrated Dryland Agricultural System), a deterministic linear programming model which has been described in detail by Penrell et al. (1984) and Kingwell (1987) and applied to a wide range of problems (e.g. Ghoshal and Penrell 1987; Penrell and Ghoshal 1988; Ghoshal and Penrell 1991). MUDAS represents climatic uncertainty through the inclusion of nine discrete weather types. Each of these seasons is represented by a substrate of comparable detail to the deterministic MUDAS model.

The criteria for classifying seasons areas firstly, from discussions with farmers to identify which seasonal features influence their farm strategies and adjustment decisions and secondly, from detailed summaries of climatic characteristics of actual seasons from 1912 to 1988. This resulted in four criteria being identified: the timing of opening rains, the incidence of summer rain, the type of opening rains received and the level of spring rainfall.

The most important climatic factor influencing farm management decisions is the timing of opening rains. The later a crop is sown the shorter the growing season before rainfall ceases and the sooner its experiences unfavourable growing conditions such as shortening day length and low temperatures. Consequently late-sown crops have a relatively low yield potential and, in seasons permitting early sowing, yield potential is high. Seasons in MIDAS are categorized as early, mid or late.

The amount of rainfall in summer and early autumn is also an important influence on crop area adjustment decisions. These rains provide reserves of stored soil moisture and increase expected crop yields. The incidence of summer rain fix is defined by three to be high or low.

Two types of opening rains are represented, characterized by the presence or absence of light rainfall before the main opening rains. These early rains are not sufficient to allow sowing on frontier soils but do allow earlier sowing of crops on smaller soils.

Spring rainfall is characterized as being high or low. This affects (final) yields but is not a major influence on decision making as it occurs after most management decisions have been made.

The four criteria allow for 24 (12 x 2 x 2) plausible types of season, however applying the criteria to rainfall statistics for Warradigby from 1912 to 1988 showed that none of the possible seasons are yet to be observed and some have occurred so infrequently as to warrant their inclusion in clearly

related groups. Even where some seasons could be differentiated by these criteria, a simulation modelling showed that there was little impact on yield, allowing further grouping of seasons. A final set of nine season types with associated relative frequencies was selected as representative of season variation in the region (Table 1).

Table 1. Season Types in MUDAS

Season	Seeding time	Summer rain	Spring rain	Earlier sowing on sandy soils	Season probability	Typical wheat yield (tonnes/ha)
1	early	high	either	no	0.17	1.86
2	early	low	high	no	0.12	1.22
3	early	low	low	no	0.08	0.84
4	mid	high	either	yes	0.05	1.60
5	mid	low	either	yes	0.12	0.81
6	mid	high	either	no	0.13	1.28
7	mid	low	either	no	0.09	0.77
8	late	low	either	yes	0.14	0.61
9	late	low	either	no	0.10	0.57
				Expected yield		1.09

Strategic Activities and Constraints.

The strategic section of MUDAS describes management options to be undertaken in all seasons, unless a tactical adjustment in a particular season demands otherwise. The decision variables include the allocation of land to pasture and each crop, the rotational sequence of enterprises on each of the seven soil classes, livestock numbers, flock structure, feed sources and uses, machinery, labor and finance.

There is a set of global constraints which applies to all seasons (such as constraints which maintain a steady-state sheep flock) and a set which is repeated with different parameter values for each season type (such as pasture production parameters in each month for each type of season).

Parameters were obtained from a range of sources, including field trials, biological simulation models, scientific, economic and farming publications and subjective estimates made by appropriate experts. The data were reviewed in a lengthy process of consultation with biological researchers and advisers.

Tactical Activities and Constraints

The short-term adjustment options represented in MUDAS arose out of discussions with farmers and discussions with various advisers and researchers. The adjustment options represented are different for each season and for each soil type in accordance with the advice of our collaborators. They include changes in enterprise selection on a soil type, grazing management, sheep live weights, sheep adjustment and supplementary feeding of grain. All these options are available as tactical responses to climatic information. There are no options for tactical

responses to short term price fluctuations.

Tactical adjustments result in changes in inputs, costs and products in the year in which the adjustment occurs and some also have impacts on parameter values in subsequent years. Subsequent effects reflect the fact that one year's deviation from a rotation has an effect on subsequent soil fertility, weed densities and pasture availability. All adjustment activities are either specific to one season or to a set of seasons. If the seasons cannot be distinguished at the time of the decision,

Farmers and advisers considered that alteration of crop areas are heavy soil treatments in response to seasonal conditions was highly likely to be beneficial but that such adjustments were rare; if ever, required on light soils. Hence MUDAS includes crop area adjustments on all soils with a high clay content, but only on one of the sandier soils. Area adjustment constraints limit the nature and area of adjustment, parsimonious within a 5% added rotation. Area adjustment activities are specific to the phase of a rotation on each soil class and change herbicide and pesticide costs, tillage methods, nitrogen and phosphate fertilizer costs, the depreciation of crop gear, stable handling costs, use of limited seedling plant capacity and penalties incurred for late sowing. All such changes are calculated automatically in spreadsheets and are represented in the model as net effects (Kingwell et al., 1991).

A large set of livestock adjustments in MUDAS involves adjustment (i.e. temporary removal or stocking sheep from the farm and their placement, at cost, on pastures or dry feed elsewhere). Adjustment is often practised in periods of prolonged feed scarcity. In MUDAS, sheep other than lambs, ram and breeding ewes can be adjusted. Potential adjustment periods are June to August and September to April. Each adjustment activity is represented on a spring to feed requirement during the adjustment, allowing a reduction in stocking rate, costs of adjustment vary according to demand and supply conditions considered likely in different periods of different types of seasons.

Livestock pattern deviations, which give the farmer the option to allow sheep to gain or lose weight depending on seasonal conditions, affect feed transfer rates (due to changes to energy requirements and intake capacities), financial (due to changes in wool production per head) and sheep numbers (due to changes in lamb production per ewe). Results include activities for supplementary feeding of grain in each month of each season.

Runs for this Study

This study focuses on the value of tactical adjustments to enterprise areas rather than the other adjustments relating to fertilizer use and sheep management. This is because of the over-ridingly importance of area adjustments and the difficulty of obtaining feasible solutions if some of the sheep adjustment options are not included. The improvement in net returns resulting from adjustments to enterprise areas is referred to below as the "value of climatic information".

The model is run with area adjustment activities included and excluded from all soil types in all seasons. Changes in key variables between the two solutions are recorded. The probability distribution across seasons and the mean value of climatic information are calculated. The initial results are

for on-farm prices of A\$125 per tonnes of wheat, A\$145 per tonnes of lupins and A\$12.50 per Kilogram of greasy wool. Subsequently we test the sensitivity of these results to key commodity prices.

Table 3. Optimal Strategic Land Use and Tactical Increase in Threat Area (ha)

Results and Discussion

	Included	Excluded	Included	Excluded
	Area Adjustment Activities		Enterprise Area Adjustments	
Crop area (ha)	1472	1475		
Pasture > 6ha (ha)	828	825		
Sheep Number (head)	1559	1516		
Grain fed (tonnes)	15.3	19.5		
Grain stored to feed later (tonnes)			7.1	16.7
Wheat sold (tonnes)	1311	1191		
Wool sold (kg)	7613	9140		

The land use strategies and tactics which underlie the figures in Table 2 were shown in Table 3. Note that there are also adjustments to fertilizer levels, timing of pasture consumption, enterprise and animal live weights, pastures from the "adjustments" model). Rotational sequences of crops and pastures from the "adjustments" model are shown for each soil type. Optimal rotations are a.s. different for most soil types. This is consistent with earlier findings for this farm system using the deterministic RIBUS model (e.g. Ghadiri and Paranc 1991). Table 3 shows that when land area adjustments are allowed, the solution includes higher crop areas in seasons 1, 2, 3, 4 and 6 (factors with apparently favorable climatic conditions at sowing time) and lower areas in seasons 5, 7, 8 and 9. In other words, the strategy which is optimal if area adjustments are not allowed is not optimal in any individual season.

Most of the area adjustments occur on soils 5 and 6. In seasons with favorable early conditions, the only adjustments are higher crop areas on soil type 6. At the start of the season (less favorable), crop areas are reduced on soils 5 and 6 and in extreme cases on soil 7. In very poor seasons (8 and 9) there is also a switch of crop species on soil type 4 from lupins to wheat. This is due to the greater sensitivity of lupins to poor growing conditions. These changes in crop ranges from 40 to 74 per cent. These variations occur despite constant ex-farm commodity prices.

Table 3. Optimal Strategic Land Use and Tectical Increase in threat Area (ha)

Increase in Wheat Area (ha) if Adjustments Included*

Although the inclusion of area adjustments results in differences in every season, the extent of the differences is generally not large. In seasons 1 to 7, adjustments are made to less than 10% of the farm according to the solution with no adjustments. Only in the very worst season are there major adjustments; four soil types and 21% of the farm areas are affected in season 9.

Despite the small area affected, the impact on profits can be very significant. Table 4 shows the impact of area adjustments on annual net cash surplus (gross cash receipts minus variable production costs, fixed product ion costs and living expenses). The difference between net cash surplus with and without adjustments represents the value of climatic information used to make the adjustments. The expected value of climatic adjustments to enterprise areas increased the expected value of net cash surplus by 22 per cent.

In general, the value of climatic information is highest in the extreme seasons: the best and the worst. The largest absolute increases of \$42,864 occurs in season 1, which has the highest expected crop yield. In the worst season (9) these adjustments reduce the cash deficit from \$48,090 to \$15,800. For risk averse farmers, this increase may be of even greater significance than the larger improvements which are possible in seasons

Information.

Note that although land use is the same in seasons 1 to 4, the net cash surpluses and values of climatic information are very different between these four seasons. For example, although seasons 2 and 3 have identical climatic patterns until after the crop has been sown, season three has much lower yields due to poor finishing rains. Lower yields mean that the benefits of increasing crop area are such less (\$A3,700 compared with \$A26,800) and in some circumstances could even be negative.

Table 4. Net Cash Flow in Each Season With and Without Enterprise Area Adjustments

Season	Area Adjustment Activities		Difference
	Included	Excluded	
1	\$236,700	\$193,900	\$42,800
2	\$152,800	\$128,300	\$24,500
3	\$1,500	\$3,800	-\$2,300
4	\$182,700	\$163,700	\$19,000
5	\$42,300	\$43,300	-\$1,000
6	\$100,200	\$93,100	\$7,100
7	\$22,000	\$21,300	\$1,700
8	-\$913,600	-\$919,800	\$6,200
9	-\$315,800	-\$348,000	\$32,200
Expected value	\$83,000	\$97,800	\$15,200

The "with adjustments" model does have lower cash surplus in session 1 (no capacity within MELAS to treat seasons 6 and 7 independently), and partly because of strategic changes to sheep management which have a positive impact overall but a negative impact in session 5. The model which includes area adjustments selects a lower stocking rate of sheep on pastures. This reduces feed problems in poor seasons, increases pasture production per hectare and enhances the capacity to increase crop area in good sessions. However these advantages are obtained at the cost of slightly lower returns in session 5 due to lower wool sales.

Impact of Price Changes

The expected value of climatic information is affected by the prevailing commodity prices. Table 6 shows that the value is positively related to wheat price, but negatively related to wool price. Because cropping is a relatively more important source of income when adjustments are included (see Table 2), higher wheat prices increase the difference between expected income with and without area adjustments. Lowering the wool price also makes wheat a relatively more profitable enterprise and similarly increases the expected value of climatic information. We hypothesize that if price adjustments per se change the relative importance of an enterprise, price changes will affect the expected value of information used to make the adjustments.

Table 5. Value of Climatic Information for Different Wheat and Wool Prices

	Wheat Price* (A\$/Lonne)	Value of Information (A\$'000)	Wool Price* (A\$/kg)	Value of Information (A\$'000)	Wool gate price net of all selling and transport costs, wool price fixed at A\$2.00 for wheat price sensitivity. Wheat price fixed at A\$125 for wool price sensitivity.
	85	105	1.30	1.30	2.10
	10.8	13.1	17.3	17.3	2.90
	16.2	16.9	19.3	15.2	3.70
	17.9	13.7	21.3	13.7	4.50

Effect of Adjustments on Supply Elasticities

As well as changing the expected levels of production of different commodities, use of climatic information can also affect the responsiveness of producers to price changes. Table 6 shows own price supply elasticities estimated with the model for wheat and wool. These are obtained by solving the model for a range of prices and re-estimating these prices against the expected value of quantities produced (using QLS).

The own price supply elasticity for wool is lower when area adjustments are included. However the adjustments have no impact on the own price supply elasticity for wheat. The change in elasticity for wool is not due to risk aversion; all solutions in this paper are for maximum expected profit. Rather it appears that the lower price elasticity when adjustments to season are included is due to lower stocking rate. Price changes have a smaller impact on profitability per hectare if the stocking rate is lower. In effect, the lower elasticity is due to the increased significance of climate in determining land use. The scope for price responses is less when responses to climatic conditions must also be made.

Table 6. Effect of area adjustments on own price elasticity of supply*

Area Adjustment Activities	Own Price Elasticity	
	Included	Excluded
Wheat	0.46	0.49
Wool	0.85	0.72

*Based on farm gate price net of all selling and transport costs.

Elasticities calculated at A\$2.00 and wheat price of

A\$125.

Concluding Comments

Simple adjustments in enterprise areas can result in substantial improvements in expected profit on farms in the subject region. In the standard model, use of climatic information increases expected net returns by approximately 22 per cent. The benefits are not evenly distributed

across different season types but occur predominantly in the best and worst seasons. The magnitude of benefits is affected differently by different commodity prices. Benefits are due to capitalizing on knowledge about the greater volatility of profits from cropping than from sheep production. Crops are relatively more profitable in good seasons and relatively less profitable in poor seasons. Deterministic models and even stochastic models which don't include activities for tactical adjustments miss this key feature of the system.

Nevertheless, as Kingwell et al. (1991) noted, activities selected by the deterministic model MIDAS are reassuringly similar to those from MUDAS, indicating that long term average land use in the region is little affected by tactical adjustments. Deviations from the deterministic solution tend to cancel out so that the MIDAS model is able to identify near optimal solutions for long term rotations. This is important for practical purposes given the far greater ease of using MIDAS and the relative scarcity of hardware capable of solving MUDAS.

Potential improvements to the model include representation of risk aversion and inclusion of a wider range of season types. Risk aversion is likely to affect the strategies selected and may also affect the tactical adjustment activities. Inclusion of the Utility Efficient Programming approach to modeling risk is planned (Patten et al. 1988). Inclusion of further season types would allow finer resolution in selecting tactics and would reduce problems of associating an actual season with one of the discrete season types in MUDAS for extension purposes.

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