# The Role of Tactical Decision-making and Risk Aversion in affecting a Farmer's Response to Price Stabilization

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## Introduction

In constructing any model of farm management it is usually acknowledged that the model cannot represent fully the complexity of farming (Kennedy *et al.*, 1994). Even representing the main features of farming is an art (Hardaker *et al.*, 1991). Several studies (Schroeder and Featherstone, 1990; Chavas and Holt, 1990; Featherstone *et al.*, 1993; Mafoua-Koukebene *et al.*, 1996) suggest that it is necessary for a farm model to include risk aversion when the modelling objective is to predict farmer behaviour. Other studies (e.g. Antle, 1983; Kingwell *et al.*, 1993; Marshall, 1996) identify tactical decision-making also as an important feature of farm management. Antle, for example, argues that "dynamic, risk-neutral models may be more useful than conventional static, risk-averse models for understanding the role production risk plays in farm management." (p.1099).

This paper explores the role and relative importance of risk aversion *and* tactical decision-making in a farm management model designed to examine farmer responses to price stabilization for wheat and wool. The model is a discrete stochastic programming model of a representative wheat-sheep farm in a region of Australia. The model describes in some detail the nature of the farming system; the stochastic nature of production outcomes associated with weather-years, the main tactical decisions that arise sequentially as a weather-year unfolds, the interactions between crop and livestock enterprises and the output price uncertainty facing the farmer.

This model is used to examine the farm-level effects of price stabilization for wheat and wool. Besides reporting these effects this paper focuses on the role of tactical decision-making and risk aversion in affecting a farmer's response to price stabilization for wheat and wool. The first section of the paper describes how price stabilization schemes for wheat and wool can be represented in a discrete stochastic programming model. The second section describes the farming system and the representative farm model of that system. The third section presents modelling results. These results are discussed and the paper concludes about the role and relative importance of risk aversion and tactical decision-making in affecting a farmer's response to price stabilization.

## Modelling Price Effects of the Schemes

The reserve price scheme for wool and the minimum guaranteed price scheme for wheat have both been modelled as a winsorisation of normal distributions of prices (Fraser, 1988; Murrell, 1991; Fraser, 1993). This modelling approach can be criticized on a few main grounds.

Firstly, the approach assumes prices subject to winsorisation are initially normally distributed yet empirical evidence, at least for wool, points to prices being positively skewed (Hinchy and Fisher, 1988; Bardsley and Olekalns, 1996). In general, the prices of storable commodities such as wool are likely to display positive skewness (Williams and Wright, 1991). Further, the assumption of prices being normally distributed prices is inconsistent with the non-negativity requirement for price. In light of these criticisms a preferable function to describe the prices would be the lognormal which incorporates a positive skew and which satisfies the non-negativity requirement for prices.[1]

The modeling approach of Fraser and Murrell as applied to the reserve price scheme also can be criticised for its assumption that this scheme was a symme rical price band scheme. In practice occasionally the Australian Wool Corporation's stockpile (particularly of finer wools) was so small as to have little impact on containing upwai ! movements in wool prices.[2] Admittedly the Australian Wool Corporation's policy of quitting wools from the stockpile during periods of high prices reduced the probability of stockouts and thereby reduced the probability of very high prices. However, the probability of very high prices was not reduced to zero as is assumed with an upper bound on prices.

In light of the criticisms of the modeling approach of Fraser and Murrell, this paper makes the following assumptions about wheat and wool price distributions. Both wool and wheat prices in the absence of the marketing schemes are assumed to be lognormally distributed. The guaranteed minimum price scheme is assumed to act as a lower bound winsorisation of a lognormal distribution of price as described in appendix one. The reserve price scheme is assumed also to provide a lower bound on wool prices and to reduce the probability of very high wool prices (but does not provide an upper bound). The particular distribution characteristics are presented in Table 1 and include each wool class from 20 to 23 micron.

(Table 1)

The distributions in Table 1 can be represented as discrete price states by a method outlined in appendix two. The method formulates the approximation of continuous distributions by discrete states as a non-linear programming problem and is an equally accurate alternative to Gaussian quadrature (Preckel and DeVuyst, 1992). The discrete price states generated by this method are presented in Table 2. Each distribution is characterised by 5 price states.

(Table 2)

## Modelling Farm-level Effects of the Schemes

To examine the farm-level effects of the marketing schemes for wheat and wool the price states in Table 2 are incorporated in a representative farm model of wheat and sheep production for a region of Australia. Before describing this model the farming system represented in the model is described briefly.

### *Farming System*

The region selected as typical of wheat and wool producing regions within Australia is the Merredin region of Western Australia (see Figure 1). This is an inland area of approximately 33,500 square kilometres. The region contains about 1150 farms almost all of which are

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[1] Hertzler and Coad (1996), for example, adopted the assumption that wheat prices are lognormally distributed and the same assumption is usec .n this paper.

[2] For example, in June 1988 the Australian Wool Corporation's entire stockpile was only 9 thousand bales; a trifling amount compared to the 4.6 million bales it held at the end of 1990.

mixed enterprise businesses mainly producing wheat, wool and sheep for export as live animals. Typically a farm in the Merredin region is owner-operated with not more than one other permanent labourer. Casual or contract labour is hired for only a few months of the year to assist in main tasks such as seeding, harvesting and shearing. Most farm operations are highly mechanised and average farm size is around 2700 hectares.

(Figure 1)

Crops, mainly wheat and lupins, are sown from late April until early July, depending on seasonal conditions, and are harvested from late November until very early January. Weed control for cropping is by tillage and chemical spraying using pre and post-emergent herbicides. Phosphatic and nitrogenous fertlizers are applied to most cereal crops. These crops are harvested and the grain is transported by the farmer or contractors to off-farm storage. A portion of the harvested lupin grain is normally retained on-farm for subsequent use as a feed grain in autumn when paddock feed is of poor quality and sheep require supplementary feeding.

The main sheep breed in the region is the Merino. These are large framed animals which produce adult fleeces in the range of 20 to 22 micron (Bell and Ralph, 1993), each fleece weighing between 4 to 6 kilograms. Lambing is in late autumn or winter and shearing is in spring and autumn. All lambs have their tails removed and male lambs are castrated. Young wethers are sold for export as live animals while ewes are kept for wool and lamb production, eventually being sold for mutton. Sheep are run on annual pastures during winter and on a combination of crop residues and dry annual pastures in summer (Ferguson, 1981; Bell and Ralph, 1993). In autumn often feed quality in the paddocks deteriorates to such an extent (Belotti *et al.*, 1993) that supplementary feeding, often with lupins or oats, is required (Rowe, 1992). The quality and quantity of paddock feed, especially autumn feed, affects sheep liveweights (Tomes and Fairnie, 1981; Purser and Southey, 1984) and restricts a farm's carrying capacity.

*Representative Farm Model*

The representative farm model describing the farming system of the Merredin region, and the impact of the marketing schemes, is a discrete stochastic programming (DSP) model. DSP models are becoming more common in the literature (e.g. Brown and Drynan, 1986; Lambert and McCarl, 1989; Schroeder and Featherstone, 1990). Advances in computing speed and capacity have facilitated their construction and use. Previously the 'curse of dimensionality' limited DSP applications (Featherstone *et al.*, 1993).

The DSP model of a representative Merredin farm considers 11 weather-year states and 5 price states; forming 55 terminal states. The model's objective function is the maximization of expected utility where utility is defined by a CRRA utility function. The objective function is:

$$(1.1) \quad \text{Max } E[U(x)] = \sum_{t=1}^{n} S_t((W_0 + \pi_t)^{(1-R_r)} / (1 - R_r))$$

where $W_0$ is initial wealth,

$\pi_t$ is profit at terminal state t,

$S_t$ is the probability of occurrence of ending at terminal state t,

$R_r$ is the relative risk aversion coefficient and

n is the number of terminal states that are 55 states of nature; 11 weather-year states by 5 price states.

$R_r$ is set to describe a range of risk behaviour; $0 < R_r \leq 2.5$. Estimates of $R_r$ for Australian broadacre farmers are typically that $0 < R_r < 1.5$ (Bond and Wonder, 1980; Bardsley and Harris, 1987&1991).

A key assumption of DSP is that some decisions are made after a state of nature is observed (Hazell and Norton, 1986). This implies that the farm manager has scope for either avoiding losses in some circumstances or profiting from an unfolding event as illustrated in Figure 2.

(Figure 2)

The discrete events or states of nature in Figure 2 are shown as diamond shapes and are weather conditions in summer and autumn. In this illustration summers are classed as being wet or dry and autumns can be very dry, usual or wet. The two weather possibilities for summer followed by the three weather possibilities for autumn mean there are 6 (2x3) possible states of nature. Facing these states of nature the farmer makes a series of sheep and crop management decisions that are represented as star shapes. There are decisions about sheep flock size and structure, the buying and selling of feed, the buying and selling of sheep and the areas to commit to crop or pasture.

The DSP model of the representative Merredin farm describes: (a) the stochastic nature of production outcomes associated with weather-years, (b) the main tactical decisions that arise sequentially as a weather-year unfolds and (c) the discrete price states for wheat and wool price distributions in the presence and absence of the marketing schemes.

Incorporating weather-year variation within the model was necessary because this variation greatly affects wheat and pasture production and enterprise management. Wheat and pasture yields and the carrying capacity of a farm are affected by weather-year variation. Another important feature of the wheat-sheep farming system represented in the model is the tactical management of the wheat and sheep enterprises by farmers.

In some detail the model describes the nature of farm resources that constrain or affect farm management decisions, the biology of the farming system and the interactions between the crop, pasture and sheep enterprises. The model describes the main rotation options on each of seven soil classes, the feed requirements, liveweight and production patterns for each of over 20 sheep classes and the tactical changes in crop and pasture areas, sheep feeding, agistment and fertiliser rates of application. A full model description is contained in Kingwell (1996). The 11 final weather-year states are listed in Table 3.

(Table 3)

Data and model size restrictions invariably cause simplification of the representation of the decision-making process and the uncertainty surrounding outcomes. Several recommendations are offered in the literature (Anderson *et al.*, 1977; Featherstone *et al.*, 1990; Hardaker *et al.*, 1991) about preferred means of simplification. Several of these recommendations were adopted to reduce model size thereby allowing the model to comprise 2079 activities, 1661 rows and 60765 matrix elements (density of 1.759 percent).

The model was solved using AESOP, a non-linear version of MINOS developed for microcomputers by Murtagh and Saunders (1983). Mathematical programming support software developed by Pannell (1988) was used to test, revise and apply the model. The model was run on a Pentium 100 Mhz microcomputer with 16 MB RAM and the input file was 1.956 MB. Given a solution basis the model generally solved in less than 10 minutes.

**Modelling Results**

Using the farm model to examine the farm-level effects of price stabilization, three main findings emerge. The most important of these findings concerning the role and relative importance of risk aversion and tactical decision-making is discussed last. The first finding is that, when the optimal solutions of the farm model *with* and *without* the price stabilization schemes are compared, then the welfare of risk neutral and risk averse farmers is improved only slightly by the schemes. As shown in Table 4 the certainty equivalent of terminal wealth increases by about 0.7 per cent for a risk neutral farmer versus 1.0 per cent for a very risk averse farmer ($R_r = 2.5$).

(Table 4)

This finding that the welfare of risk neutral and risk averse farmers is improved only slightly by the marketing schemes is underpinned by several assumptions. One of the more important assumptions is the conservative management of the reserve price scheme. This did not occur and it has cost the wool industry dearly (Malcolm, 1994). The small welfare gains associated with schemes as identified in this study in practice would have been eroded quickly by the actual incautious management of the reserve price scheme in the late 1980s.

The small gains from stabilization, even with conservative management, and the huge costs incurred when such management is not adopted suggest that price stabilization schemes may not be as desirable as once thought. The fact that the World Bank is now reluctant to support price stabilization schemes (Anderson and Hazell, 1996) is evidence of the consensus that such schemes often offer minor benefits compared to the immense transfer costs that can arise if price supports are set incautiously.

A second finding from results in Tables 5 and 6 is that the ability to adjust crop areas more substantially improves farmer welfare than the provision of the marketing schemes. Marketing schemes boost profit by less than 13 per cent *with* or *without* the inclusion of tactical adjustments to crop and pasture areas. However, *with* or *without* the marketing schemes farm profit increases by around 30 per cent due to inclusion of tactical adjustments.

(Tables 5&6)

Results in Table 7 show that when tactical adjustment of crop and pasture areas is excluded, optimal farm plans are characterised by fewer sheep, less pasture area, a lower stocking rate, more wheat area and usually more lupin area and agistment. Being constrained to a strategic selection of crop and pasture areas means the farmer cannot fully capitalise on the more favourable weather-years in which higher pasture production supports both greater stocking rates and allows some pasture area to be used for wheat production. A strategic increase in the area of wheat generates increased profit in the more favourable weather-years at cost of some combination of lower stocking rates, increased agistment and extra supplementary feeding per animal in the less favourable weather-years. The optimal farm plans and their profitability *with* and *without* area adjustments are substantially different and indicate that these adjustments can add greatly to farmer welfare. By contrast, optimal farm plans in the presence of the schemes and *with* or *without* crop area adjustment are only slightly more wheat dominant. For example, given risk neutrality, the expected wheat area increases by 9 hectares in the presence of the schemes when area adjustment is permitted. When area adjustment is excluded the wheat area increases by only 4 hectares. The important contribution to farm profit from tactical decisions is a common finding in the literature (e.g. Antle, 1983; Mjelde and Cochran, 1988; Schroeder and Featherstone, 1990; Mazzocco, 1992;

Kingwell *et al.*, 1993; Mjelde and Dixon, 1993; Taylor, 1993; Dorward, 1994; Marshall, 1996).

The third and major finding is that risk neutral versus risk averse farmers have opposite production responses to the presence of the schemes when these farmers are able to respond tactically to unfolding weather-year conditions. Risk neutral farmers increase their wheat area while even slightly risk averse farmers decrease their wheat area.[3] For example, for a risk neutral farmer in the presence of the schemes, sheep numbers are 1.3 per cent less, pasture area is 0.3 per cent less while the wheat area is 1.1 per cent greater. The guaranteed minimum price scheme for wheat results in the expected price for wheat increasing relative to the expected price for wool. The risk neutral farmer responds to these changes in the relative expected prices for wheat and wool by shifting resources into wheat production.

By contrast, a slightly risk averse farmer ($R_r = 0.5$) in the presence of the schemes plants 1.1 per cent less wheat and 0.7 per cent more pasture. The risk averse farmer switches resources into wool production mainly due to the effectiveness of the reserve price scheme acting to greatly reduce wool price uncertainty, particularly in the lower micron classes which also have higher expected prices. Further, the nature of wool production is such that it provides a risk averse producer with more opportunity, relative to wheat growing, to generate income in low-income weather-years and thereby lessen income variance across weather-years. The end result is a decline in the area of wheat and wheat production while the area of pasture and sheep and wool production increase.

These results concerning predicted production responses are opposite in direction to those found by Fraser (1993) and the level of response with respect to land allocation is nowhere near as great as suggested by Fraser. For scheme and production assumptions most relevant to those examined in this paper Fraser found that removing price stabilization for wheat and wool would cause a risk averse producer ($R_r = 0.7$) of 21 or 23 micron wool to shift out of wheat production into wool.[4] Specifically, he found that removal of the schemes would lead to the allocation of land in wheat falling from 50 per cent to 38.8 and 3 per cent for 21 and 23 micron wool producers respectively.

The difference in results is mainly due to the simplicity of Fraser's model which overlooks the tactical nature of farm management and the biological complexity and resource endowment of a typical farm.[5] In the farm model presented in this paper, when adjustment of crop area is excluded, then at any level of risk aversion the area of wheat in the presence of the schemes is always greater than that in the absence of the schemes. Hence, when adjustments are excluded farmer behaviour is the same as predicted by Fraser.

## Discussion and Conclusion

Results tabled in this paper suggest that if a farm management model considers the marketing schemes yet ignores risk aversion then model output will misspecify production outcomes. Elaborating this point, the risk neutral case indicates that the marketing schemes result in more resources being allocated to wheat production. However, if risk aversion is included then the production response is a shift of resources into sheep production. Further, exclusion of risk aversion will lead to an underestimation of the value of the marketing schemes. As shown in Table 5 the marketing schemes generate a larger proportionate increase in the welfare of risk averse farmers compared to risk neutral farmers.

[3] Kingwell (1996) shows that the switch in direction of response occurs for farmers with $R_r > 0.3$.
[4] In the Merredin region most wool produced is in the 21 to 23 micron range.
[5] However, Fraser was aware of the shortcomings of his approach (see p. 41, Fraser (1993)).

If the marketing schemes form part of the farmer's decision environment, yet are excluded from the farm management model, then production outcomes are misspecified and farmer welfare as measured by certainty equivalents is underestimated by around $7000. This applies to the risk neutral and risk averse cases.

More important, however, are the consequences of excluding adjustment of crop area. Failure to include these adjustments results in optimal farm plans being misspecified and farmer welfare being further underestimated. For example, in the case where $R_r$ is 1.5 then the certainty equivalent difference is $11300 and $9800 in the *with* and *without* marketing scheme cases respectively.

In concert, these findings illustrate the relative importance of including tactics versus risk aversion in a farm model. Although tactical decisions, more than risk aversion, are found to substantially influence the nature and value of farm management, results show that unless tactics *and* risk aversion are both included then farmer behaviour will be misspecified.[6]

In practice, exactly how often and by how much the benefits of including both tactical response options and risk aversion in a farm model are greater than the benefits of including either is an empirical question to be answered as further evidence emerges. In general, inclusion of tactics increases the size of a model and the cost and time for model development relative to that for representing risk aversion. Thus, the benefits from including tactics need to be much greater than the benefits of including risk aversion to warrant the inclusion of tactics. However, this study shows that correctly predicting the direction and magnitude of response to price stabilization, and the welfare benefits of price stabilization, requires that tactics *and* risk aversion are both included in the farm management model.

**References**

Anderson, J.R., Dillon, J.L. and Hardaker, B.(1977) Agricultural Decision Analysis, Iowa University Press, Ames, 344pp.
Anderson, J.R. and Hazell, P.B.R (1996) Risk considerations in agricultural policy making. EUNITA Seminar-Risk Management Strategies in Agriculture: State of the Art and Future Perspectives, Jan 7-10, Wageningen, Netherlands.
Antle, J.M.(1983) Incorporating risk in production analysis. American Journal of Agricultural Economics 65:1099-1106.
Bardsley, P. and Harris, M.(1987) An approach to the econometric estimation of attitudes to risk in Australia. Australian Journal of Agricultural Economics 31:112-126.
Bardsley, P. and Harris, M.(1991) Rejoinder: An approach to the econometric estimation of attitudes to risk in Australia. Australian Journal of Agricultural Economics 35:319.
Bardsley, P. and Olekalns, N.(1996) Wool price variability in the long run. Australian Journal of Agricultural Economics 40:51-62.
Bell, K.J. and Ralph, I.G.(1993) Current sheep management: Western Australia. pp.60-66 In Proceedings of a national workshop on "Management for wool quality in Mediterranean environments", Perth, Western Australia, Nov 4-5, 1992.
Bellotti, W., Collins, W. and Moore, A.(1993) The Mediterranean environments. pp50-59 In Proceedings of a national workshop on "Management for wool quality in Mediterranean environments", Perth, Western Australia, Nov 4-5, 1992.

[6] Excluding risk aversion would cause the model to not give due weight to the risk-reducing benefits of diversification, although diversification can from part of a risk neutral strategy (Brink and McCarl, 1978; Kingwell, 1994).

Bond, G. and Wonder, B.(1980) Risk attitudes amongst Australian farmers. Australian Journal of Agricultural Economics 24:16-34.

Brink, L. and McCarl, B.(1978) The tradeoff between expected return and risk among cornbelt farmers. American Journal of Agricultural Economics 60:259-63.

Brown, C.G. and Drynan, R G. (1986) Plant location analysis using discrete stochastic programming. Australian Journal of Agricultural Economics 30:1-22.

Chavas, J-P. and Holt, M.T.(1990) Acreage decisions under risk: the case of corn and soybeans. American Journal of Agricultural Economics 72:529-38.

Dorward, A.(1994) Farm planning with resource uncertainty: a semi-sequential approach. European Review of Agricultural Economics 21:309-324.

Featherstone, A.M., Baker, T.G. and Preckel, P.V.(1993) Modeling dynamics and risk using discrete stochastic programming: a farm capital structure application, Chapter 10 In Applications of Dynamic Programming to Agricultural Decision Problems, (Ed. C. Robert Taylor), Boulder: Westview Press.

Ferguson, K A.(1981) Nutrition and wool production — quantity and quality of feed and quantity and quality of wool In Sheep Nutrition, (Eds: G. Tomes and I. Fairnie), Curtin University (formerly the Western Australian Institute of Technology), Hayman Road, Bentley, Western Australia.

Fraser, R.W.(1988) A method or evaluating supply response to price underwriting. Australian Journal of Agricultural Economics 32:22-36.

Fraser, R W.(1993) Welfare effects of and supply responses to recent Australian agricultural policy changes. Review of Marketing and Agricultural Economics 61:41-7.

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 59:9-22.

Hazell, P.B.R. and Norton R.D.(1986) Mathematical Programming for Economic Analysis in Agriculture, MacMillan, New York, 400pp.

Hertzler, G. and Coad, A.(1996) Financial risk management for Australian wheat gowers. Invited paper presented to the 40th annual conference of the Australian Agricultural and Resource Economics Society, Feb 11-16, University of Melbourne, Melbourne.

Hinchy, M. and Fisher, B.(1988) Benefits from price stabilization to producers and processors: the Australian buffer-stock scheme for wool. American Journal of Agricultural Economics 70:604-15.

Johnson, N.L. and Kotz, S.(1970) Continuous Univariate Distributions - 1, Houghton Mifflin Company, Boston, 300pp.

Johnson, N.L. and Kotz, S.(1972) Distributions in Statistics: Continuous Multivariate Distributions, John Wiley and Sons, New York.

Kennedy, J.O.S., Hardaker, J.B. and Quiggin, J.(1994) Incorporating risk aversion into dynamic programming models:comment. American Journal of Agricultural Economics 76:960-64.

Kingwell, R.(1994) Risk attitude and dryland farm management. Agricultural Systems 45:191-202.

Kingwell, R. (1996) Using mathematical programming to model farmer behaviour under price and seasonal uncertainty: an analysis of stabilization policies for wheat and wool, unpublished PhD thesis, University of Western Australia.

Kingwell, R.S., Pannell, D.J. and Robinson, S.(1993) Tactical responses to seasonal conditions in whole-farm planning in Western Australia. Agricultural Economics 8:211-226.

Lambert, D.K. and McCarl, B.A.(1989) Sequential modelling of white wheat marketing strategies. North Central Journal of Agricultural Economics 11:105-115.

Mafoua-Koukebene, E., Hornbaker, R.H. and Sherrick, B.J.(1996) Effects of government program payments on farm portfolio diversification. Review of Agricultural Economics 18:281-291.

Malcolm, B.(1994) Australian agricultural policy since 1992: new emphases, old imperatives. Review of Marketing and Agricultural Economics 62:143-165.

Marshall, G.R.(1996) Risk attitude, planting conditions and the value of climate forecasts to a dryland wheat grower. Unpublished M.Ec. thesis, University of New England, Armidale, Australia.

Mazzocco, M.A., Mjelde, J.W., Sonka, S.T., Lamb, P.J. and Hollinger, S.E.(1992) Using hierarchical systems aggregation to model the value of information in agricultural sytems; an application for climate forecast information. Agricultural Systems 40:393-412.

Miller, A.C. and Rice, T.R.(1983) Discrete approximations of probability distributions. Management Science 29:352-362.

Mjelde, J.W. and Cochran, M.J.(1988) Obtaining lower and upper bounds on the value of seasonal climate forecasts as a function of risk preferences. Western Journal of Agricultural Economics 13:285-293.

Mjelde, J.W. and Dixon, B.L.(1993) Valuing the lead time of periodic forecasts in dynamic production systems. Agricultural Systems 42:41-55.

Murrell, A.J.(1991) Does the producer benefit from price stabilisation ? An empirical analysis of the Australian Wool Corporation's reserve price scheme. Unpublished PhD thesis, Department of Agricultural Economics, University of Western Australia.

Murtagh, B.A. and Saunders, M.A.(1983) Minos V Users Guide, Technical Report SOL 83-20, Systems Optimization Laboratory, Department of Operations Research, Stanford University, Connecticut.

Pannell, D.J.(1988) An integrated package for linear programming. Review of Marketing and Agricultural Economics 56:234-235.

Preckel, P.V. and DeVuyst, E.(1992) Efficient handling of probability information for decision analysis under risk. American Journal of Agricultural Economics 74:654-662.

Purser, D.B. and Southey, I.(1984) In Wool Production in Western Australia, p.99, (Eds: S. Baker, D. Masters and I. Williams), Australian Society of Animal Production (WA Branch), Perth.

Rowe, J.(1992) Supplementary feeding of sheep and cattle in Western Australia: survey results, Miscellaneous publication, Feb 1992, Department of Agriculture (Western Australia), Baron-Hay Court, South Perth.

Schroeder, T.C. and Featherstone, A.M.(1990) Dynamic marketing and retention decisions for cow-calf producers. American Journal of Agricultural Economics 72:1028-1040.

Taylor, C.R.(1993) Applications of Dynamic Programming to Agricultural Decision Problems, Westview Press: Boulder.

Tomes, G.J. and Fairnie, I.J. (Eds) (1981) Sheep Nutrition. Curtin University (formerly the Western Australian Institute of Technology), Hayman Road, Bentley, Western Australia.

Williams, J.C. and Wright, B.D.(1991) Storage and Commodity Markets. Cambridge University Press, Cambridge, UK.

Table 1. Characteristics of wheat and wool price distributions *with* and *without* price stabilization[a]

| Without Schemes | | | E[p] | Var[p] | Coeff of Variation | Correlation coeff with wheat[b] |
|---|---|---|---|---|---|---|
| Wheat | | | 187 | 833 | 15.4 | 1 |
| Wool 20 micron | | | 974 | 155455 | 40.5 | 0.12 |
| Wool 21 micron | | | 812 | 76432 | 34.0 | 0.10 |
| Wool 22 micron | | | 724 | 46811 | 29.9 | 0.10 |
| Wool 23 micron | | | 662 | 31576 | 26.9 | 0.11 |
| **With Schemes** | **Lower price censor** | **Cumulative probability at the lower price censor** | **E[p.]** | **Var[p.]** | **Coeff of Variation** | **Correlation coeff with wheat** |
| Wheat | 168.3 | .271 | 191 | 575 | 12.6 | 1 |
| Wool 20 micron | 833 | .452 | 946 | 50868 | 23.8 | 0.09 |
| Wool 21 micron | 694 | .419 | 789 | 25748 | 20.3 | 0.07 |
| Wool 22 micron | 619 | .392 | 703 | 16441 | 18.2 | 0.07 |
| Wool 23 micron | 566 | .369 | 643 | 11620 | 16.8 | 0.08 |

[a] All prices are assumed to be lognormally distributed in the absence of the marketing schemes. The lower censor price for wheat is based on 90 percent of *E[p]* where *E[p]* is the expected wheat price in the absence of the marketing scheme. The lower censor price for wool is based on 88 percent of *E[p]* for each wool type. *E[p.]* and *Var[p.]* are the expected price of the winsorised price distribution. The reserve price scheme is assumed to not act as a symmetrical price band scheme. The net cost of the scheme is assumed to cause E[p.] to be slightly less than E[p] (for explanation see Murrell, 1991 and Kingwell, 1996). Prices are expressed in constant 1994-5 dollar terms. Wool prices are in cents per kg clean. Wheat prices are in $ per tonne. To obtain farm-gate prices, deductions are necessary for the farmer's freight, wheat and wool research taxes and agent, handling and storage charges.
[b] Wheat is the Australian Standard White grade. Note the correlation coefficients recorded when the marketing schemes are present are smaller than those recorded in the absence of the schemes. This finding is a usual outcome of winsorisation (see p 113 in Johnson and Kotz, 1972).

Table 2: Discrete price states for wool and wheat[a]

| Without the schemes | Price state | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Probability | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Wool 20 micron | 630.4 | 727.4 | 847.3 | 929.2 | 1735.8 |
| Wool 21 micron | 554.9 | 613.9 | 739.2 | 819 | 1333 |
| Wool 22 micron | 525 | 554.8 | 675.5 | 736.6 | 1128.1 |
| Wool 23 micron | 460.6 | 490.5 | 678.3 | 730.6 | 950 |
| Wheat | 172.7 | 188.9 | 233.1 | 145 | 195.3 |
| **With the schemes** | | | | | |
| Probability | 0.26 | 0.185 | 0.185 | 0.185 | 0.185 |
| Wool 20 micron | 833 | 833 | 833 | 862.8 | 1423.1 |
| Wool 21 micron | 694 | 742.5 | 694 | 734.5 | 1126.2 |
| Wool 22 micron | 619 | 680.2 | 623.9 | 662.7 | 970 |
| Wool 23 micron | 566 | 566 | 590.1 | 678.5 | 855 |
| Wheat | 168.3 | 186.2 | 237.6 | 177.8 | 196.2 |

[a] Wool prices are in cents per kg clean. To obtain farm-gate prices deductions are necessary for the wool freight, wool taxes, agent's fees and handling charges. Wheat prices are in $ per tonne. To obtain farm-gate prices, deductions are necessary for wheat freight, wheat research taxes, handling and storage charges.

Table 3: A classification of final weather-year states

| Amount of summer and early autumn rain | Time of sowing wheat on clay soil | Nature and duration of sowing opport-unities | Post-sowing weather conditions | Estimate of wheat yield[a] on clay soil (t/ha) | CV[b] (%) | Estimate of wheat yield[a] on sandy-loam soil (t/ha) | CV[b] (%) | Prob-ability |
|---|---|---|---|---|---|---|---|---|
| much | early | clean, contin[c] | - | 2.27 | 6 | 2.18 | 5 | .067 |
| little | early | clean, contin[c] | favourable | 1.86 | 22 | 1.94 | 9 | .124 |
| little | early | clean, contin[c] | unfavourable | 1.03 | 14 | 1.03 | 14 | .079 |
| much | mid | clean, contin[c] | - | 1.90 | 18 | 1.83 | 13 | .135 |
| little | mid | clean, contin | favourable | 1.48 | 27 | 1.61 | 18 | .157 |
| little | mid | clean[d], contin | unfavourable | 0.49 | 57 | 0.76 | 52 | .067 |
| little | mid | clean[d], discont | - | 1.36 | 40 | 1.50 | 38 | .067 |
| much | late | clean[d], contin | - | 1.59 | 35 | 1.42 | 31 | .056 |
| little | late | clean, contin | favourable | 1.29 | 44 | 1.52 | 39 | .056 |
| little | late | clean, contin | unfavourable | 0.33 | 87 | 0.51 | 82 | .034 |
| little | late | patchy, contin[c] | - | 0.51 | 70 | 0.82 | 54 | .157 |

[a] Wheat yield on first day of sowing on clay soil. [b] Coefficient of variation [c] Mostly continuous
[d] Mostly clean

Note: Merredin farmers described the opportunities to commence crop sowing as being 'clean' or 'patchy'. A 'clean' start was where sufficient rainfall had fallen to allow crop sowing to commence on any soil class. A 'patchy' start was where sowing only on sandy soils (not clay soils) was permissible initially. A 'continuous' start was where rainfall was sufficient to allow crop sowing to continue. Occasionally inadequate rainfall introduced discontinuities in sowing opportunities.

Table 4: Certainty equivalents of terminal wealth *with* and *without* marketing schemes for various $R_r$ and *with* and *without* adjustment of crop or pasture areas as a weather-year unfolds ($'000)

| $R_r$ | *With* Area Adjustment *With* Schemes | *With* Area Adjustment *Without* Schemes | *Without* Area Adjustment *With* Schemes | *Without* Area Adjustment *Without* Schemes |
|---|---|---|---|---|
| 0.0 | 831.7 | 826.3 | 820.4 | 816.6 |
| 0.5 | 828.0 | 822.1 | 816.8 | 812.4 |
| 1.5 | 825.7 | 818.8 | 814.4 | 808.9 |
| 2.5 | 819.1 | 811.2 | 807.6 | 801.0 |

Table 5: Farm profit component of certainty equivalents of optimal farm plans *with* and *without* marketing schemes for various $R_r$ and plans *with* and *without* adjustment of crop or pasture areas as a weather-year unfolds ($'000)

| $R_r$ | *With* Area Adjustment *With* Schemes col 1 | *With* Area Adjustment *Without* Schemes col 2 | *Without* Area Adjustment *With* Schemes col 3 | *Without* Area Adjustment *Without* Schemes col 4 |
|---|---|---|---|---|
| 0.0 | 47.8 | 42.3 | 36.5 | 32.7 |
| 0.5 | 44.1 | 38.1 | 32.9 | 28.5 |
| 1.5 | 41.8 | 34.8 | 30.5 | 25.0 |
| 2.5 | 35.2 | 27.2 | 23.6 | 17.1 |

Table 6: Effects of adding area adjustment and marketing schemes: certainty equivalents of farm profit after addition relative to certainty equivalents of farm profit before addition; for various $R_r$[a]

| $R_r$ | Effect of adding area adjustment: *With* Schemes (1) ÷ (3) | Effect of adding area adjustment: *Without* Schemes (2) ÷ (4) | Effect of adding marketing schemes: *With* Adjustment (1) ÷ (2) | Effect of adding marketing schemes: *Without* Adjustment (3) ÷ (4) |
|---|---|---|---|---|
| 0.0 | 1.31 | 1.29 | 1.13 | 1.12 |
| 0.5 | 1.34 | 1.34 | 1.16 | 1.15 |
| 1.5 | 1.37 | 1.39 | 1.20 | 1.22 |
| 2.5 | 1.49 | 1.59 | 1.29 | 1.38 |

[a] (1),(2),(3)&(4) refer to the values in columns 1,2,3,4 in Table 5.

Table 7: Key features of optimal farm plans *with* and *without* marketing schemes for various $R_r$ and *with* and *without* adjustment of crop or pasture areas as a weather-year unfolds[a]

| $R_r$ | Activity | Unit | *With* Area Adjustment | | *Without* Area Adjustment | |
|---|---|---|---|---|---|---|
| | | | *With* Schemes | *Without* Schemes | *With* Schemes | *Without* Schemes |
| 0.0 | Pasture | ha | 1313 | 1317 | 1242 | 1242 |
| | Wheat | ha | 859 | 850 | 928 | 924 |
| | Lupin | ha | 328 | 333 | 330 | 333 |
| | Sheep | dse | 3821 | 3870 | 3518 | 3469 |
| | Stocking rate | dse per ha | 2.91 | 2.94 | 2.83 | 2.79 |
| | Agistment | hd | 65 | 77 | 64 | 125 |
| | Lupins fed | tonnes | 72 | 78 | 71 | 78 |
| 1.5 | Pasture | ha | 1365 | 1343 | 1236 | 1236 |
| | Wheat | ha | 815 | 823 | 936 | 931 |
| | Lupin | ha | 321 | 333 | 329 | 333 |
| | Sheep | dse | 4100 | 3922 | 3459 | 3417 |
| | Stocking rate | dse per ha | 3.00 | 2.92 | 2.80 | 2.76 |
| | Agistment | hd | 62 | 74 | 84 | 147 |
| | Lupins fed | tonnes | 72 | 72 | 69 | 76 |

[a] Activity levels in the table are expected values. The stocking rate is dry stock equivalents per hectare of pasture.

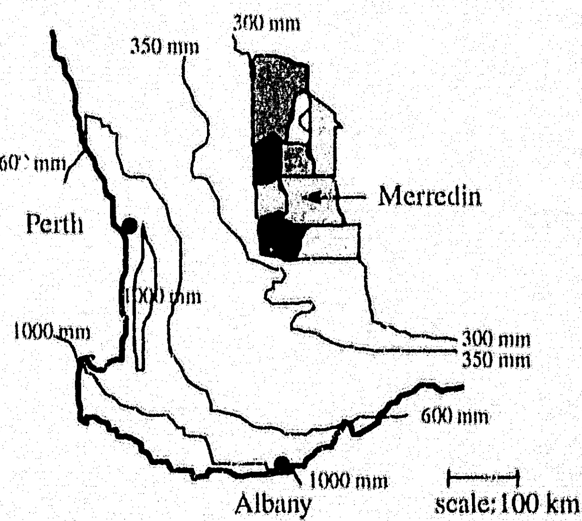


Figure 1: The Merredin region of Western Australia

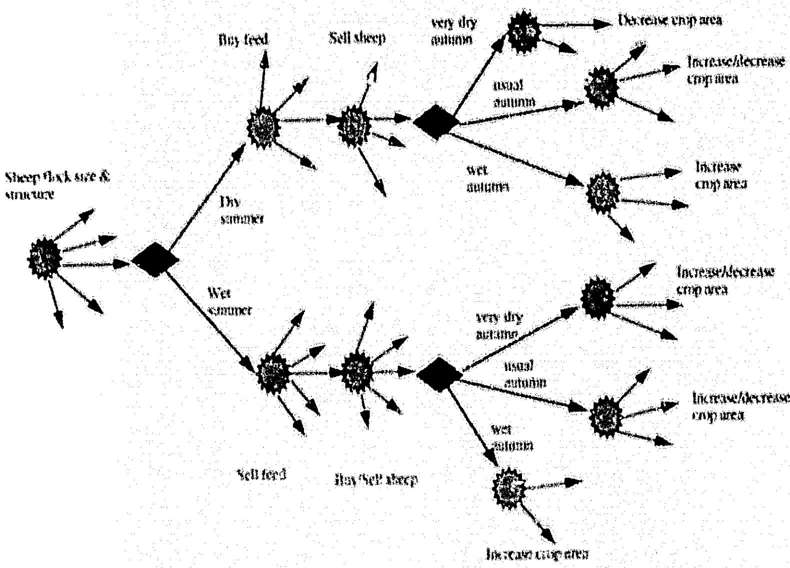


Figure 2: A decision tree showing continuous choices and discrete states of nature

## Appendix A
## Winsorisation of a lognormal distribution of price

*Lower Bound Winsorisation*

Assume the random price variable $x$ is lognormally distributed and winsorisation involves a lower censor of $x$ at point $k$, resulting in two distributions being formed. The first is a discrete distribution at the single mass point $k$. This distribution has no variance ($\sigma_1^2 = 0$) and its mean is $k$ ($\varepsilon_1 = k$). Its probability weight is $F(k)$, where $F(k)$ is the cumulative lognormal probability of $x \leq k$

The second distribution is for $x > k$ and is a lognormal distribution truncated at the lower bound $x = k$ with mean $\varepsilon_2 = E[x|x > k]$ and variance $\sigma_2^2 = Var(x|x > k)$. Its probability weight is $(1-F(k))$. Expressions for $\varepsilon_2$ and $\sigma_2^2$ are given in equations A.1 and A.2.

(A.1) $$\varepsilon_2 = e^{\mu+0.5\sigma^2}.(1-\Phi(((Ln(k)-\mu)/\sigma)-\sigma))/(1-\Phi((Ln(k)-\mu)/\sigma))$$

(A.2) $$\sigma_2^2 = e^{(2\mu+2\sigma^2)}.(1-\Phi(((Ln(k)-\mu)/\sigma)-2\sigma))/(1-\Phi((Ln(k)-\mu)/\sigma)) - e^{(\mu+0.5\sigma^2)}.(1-\Phi(((Ln(k)-\mu)/\sigma)-\sigma))/(1-\Phi((Ln(k)-\mu)/\sigma))^2$$

In equations A.1 and A.2 $\mu$ and $\sigma$ are the mean and standard deviation of the logarithmic transformation of $x$ (see chapter 14, Johnson and Kotz, 1970). These two distributions form a mixture with mean $E[x_k]$ and variance $Var[x_k]$ as given in equations A.3 and A.4 in which $x_k$ refers to values of $x$ after censoring at point $k$.

(A.3) $$E[x_k] = F(k)\varepsilon_1 + (1-F(k))\varepsilon_2$$ and

(A.4) $$Var[x_k] = (1-F(k))\sigma_2^2 + F(k)(\varepsilon_1 - \bar{\varepsilon})^2 + (1-F(k))(\varepsilon_2 - \bar{\varepsilon})^2$$

where $\bar{\varepsilon} = E[x_k]$

Expanding equations A.3 and A.4 by substituting expressions for $\varepsilon_1$, $\varepsilon_2$ and $\sigma_2^2$ yields $E[x_k]$ and $Var[x_k]$ in equations A.5 and A.6. These are the mean and variance of the winsorised lognormal distribution. Because the logarithmic transformation, $Ln(x)$, is normally distributed, the probability of $x > k$ can be re-expressed as a cumulative normal probability, $(1-\Phi((ln(k)-\mu)/\sigma))$. Hence in equations A.3 and A.4 $F(k)$ is $\Phi((ln(k)-\mu)/\sigma))$ and $(1-F(k))$ is $(1-\Phi((ln(k)-\mu)/\sigma))$.

(A.5) $$E[x_k] = \Phi((\ln(k)-\mu)/\sigma).k + .e^{\mu+0.5\sigma^2}.(1-\Phi(((\ln(k)-\mu)/\sigma)-\sigma))$$

(A.6)
$$Var[x_k] = (1-\Phi((\ln(k)-\mu)/\sigma)).(e^{(2\mu+2\sigma^2)}.(1-\Phi(((\ln(k)-\mu)/\sigma)-2\sigma))/ (1-\Phi((\ln(k)-\mu)/\sigma)) - (e^{(\mu+0.5\sigma^2)}.(1-\Phi(((\ln(k)-\mu)/\sigma)-\sigma))/ /(1-\Phi((\ln(k)-\mu)/\sigma)^2)) + (1-\Phi((\ln(k)-\mu)/\sigma)). (e^{\mu+0.5\sigma^2}.(1-\Phi(((\ln(k)-\mu)/\sigma))-\sigma))/(1-\Phi((\ln(k)-\mu)/\sigma))) - E[x_k])^2 + \Phi((\ln(k)-\mu)/\sigma).(k^2 - 2kE[x_k] + E[x_k]^2)$$

*Lower and Upper Bound Winsorisation*

Assume the random price variable $x$ is lognormally distributed and winsorisation involves a lower censor of $x$ at point $k$ and an upper censor at point t then three distributions are formed. The first is a discrete distribution at the single mass point $k$. This distribution has no variance ($\sigma_1^2 = 0$) and its mean is $k$ ($\varepsilon_1 = k$). Its probability weight is $F(k)$, where $F(k)$ is the cumulative lognormal probability of $x \leq k$.

The second distribution is for $t > x > k$ and is a lognormal distribution truncated at the lower and upper bounds $x = k$ and $x = t$ with mean $\varepsilon_2 = E[x|t > x > k]$ and variance $\sigma_2^2 = Var(x|t > x > k)$. Its probability weight is $(F(t)-F(k))$. The third distribution is a discrete distribution at the single mass point $t$. This distribution has no variance ($\sigma_1^2 = 0$) and its mean is $t$ ($\varepsilon_t = t$). Its probability weight is $(1-F(t))$, where $F(t)$ is the cumulative lognormal probability of $x \leq t$

Expressions for $\varepsilon_2$ and $\sigma_2^2$ are given in equations A.7 and 3.8.

(A.7) $$\varepsilon_2 = e^{\mu+0.5\sigma^2}.(\Phi(((Ln(t)-\mu)/\sigma)-\sigma)-\Phi(((Ln(k)-\mu)/\sigma)-\sigma))/$$
$$(\Phi((Ln(t)-\mu)/\sigma)-\Phi((Ln(k)-\mu)/\sigma))$$

(A.8) $$\sigma_2^2 = e^{(2\mu+2\sigma^2)}.(\Phi(((Ln(t)-\mu)/\sigma)-2\sigma)-\Phi(((Ln(k)-\mu)/\sigma)-2\sigma))/$$
$$(\Phi((Ln(t)-\mu)/\sigma)-\Phi((Ln(k)-\mu)/\sigma))-$$
$$e^{(\mu+0.5\sigma^2)}.(\Phi(((Ln(t)-\mu)/\sigma)-\sigma)-\Phi(((Ln(k)-\mu)/\sigma)-\sigma))$$
$$/(\Phi((Ln(t)-\mu)/\sigma)-\Phi((Ln(k)-\mu)/\sigma))^2$$

In equations A.7 and A.8 $\mu$ and $\sigma$ are the mean and standard deviation of the logarithmic transformation of $x$. The three distributions form a mixture with mean $E[x_t]$ and variance $Var[x_t]$ as given in equations A.9 and A.10 in which $x_t$ refers to values of $x$ after censoring at points $k$ and $t$.

(A.9) $$E[x_t] = F(k)\varepsilon_1 + (F(t)-F(k))\varepsilon_2 + (1-F(t))\varepsilon_t \quad \text{and}$$

(A.10) $$Var[x_t] = (F(t)-F(k))\sigma_2^2 + F(k)(\varepsilon_1-\bar{\varepsilon})^2 + (F(t)-F(k))(\varepsilon_2-\bar{\varepsilon})^2$$
$$+(1-F(t))(\varepsilon_t-\bar{\varepsilon})^2$$

where $\bar{\varepsilon} = E[x_t]$

Expanding equations A.9 and A.10 by substituting expressions for $\varepsilon_1$, $\varepsilon_2$, $\varepsilon_t$ and $\sigma_2^2$ yields $E[x_t]$ and $Var[x_t]$ in equations A.11 and A.12. These are the mean and variance of the winsorised lognormal distribution. Because the logarithmic transformation, $Ln(x)$, is normally distributed, the probability of $t > x > k$ can be re-expressed as a cumulative normal probability, $\Phi((ln(t)-\mu)/\sigma)-\Phi((ln(k)-\mu)/\sigma)$. Hence in equations A.9 and A.10 $(F(t)-F(k))$ is $(\Phi((ln(t)-\mu)/\sigma))-\Phi((ln(k)-\mu)/\sigma))$, $F(k)$ is $\Phi((in(k)-\mu)/\sigma))$ and $F(t)$ is $\Phi((ln(t)-\mu)/\sigma)$.

(A.11) $$E[x_t] = k.\Phi((\ln(k)-\mu)/\sigma) + (\Phi((\ln(t)-\mu)/\sigma)-\Phi((\ln(k)-\mu)/\sigma).$$
$$e^{\mu+0.5\sigma^2}.\Phi(((\ln(t)-\mu)/\sigma)-\sigma)-\Phi(((\ln(k)-\mu)/\sigma)-\sigma))/$$
$$(\Phi((\ln(t)-\mu)/\sigma)-(\Phi((\ln(k)-\mu)/\sigma))-\Phi((\ln(t)-\mu)/\sigma).$$
$$(1-\Phi((\ln(t)-\mu)/\sigma))$$

(A.12) $Var[x_t] = (\Phi((\ln(t) - \mu)/\sigma) - \Phi((\ln(k) - \mu)/\sigma)).\sigma_2^2 +$
$\Phi((\ln(k) - \mu)/\sigma).(k^2 - 2k\bar{\bar{\varepsilon}} + \bar{\bar{\varepsilon}}^2) + (\Phi((\ln(t) - \mu)/\sigma) - \Phi((\ln(k) - \mu)/\sigma)).$
$(t^2 - 2t\bar{\bar{\varepsilon}} + \bar{\bar{\varepsilon}}^2)$

where $\sigma_2^2$ and $\bar{\bar{\varepsilon}}$ are as defined above.

## Appendix B
## Discrete Approximation of Continuous Distributions

According to Miller and Rice (1983) the criterion for the accuracy of a discrete approximation is that it should preserve as many moments of the original distribution as possible. This criterion has intuitive appeal and infers that a discrete approximation should have the same mean, variance, skewness and kurtosis as the original continuous distribution.

The main moments of a continuous distribution can be accurately represented using Gaussian quadrature. In practice Gaussian quadrature has been applied rarely in the agricultural economics literature (see Featherstone, Preckel and Baker (1990), Preckel and DeVuyst (1992)) and less accurate approximation methods (e.g. using means of intervals) remain preferred approximation methods in many applied studies due to their ease of use.

Another method for accurately approximating a continuous distribution with discrete states uses non-linear programming. The approximation problem stated as a non-linear programming problem is as follows.

(B.1) Minimize $\int_a^b x^{k^*} f(x)dx - \sum_{i=1}^{n} p_i (x_i)^{k^*}$

subject to:

$$\int_a^b x^k f(x)dx - \sum_{i=1}^{n} p_i (x_i)^k = 0 \qquad \text{for } k < k^*$$

$$\int_a^b x^{k^*} f(x)dx - \sum_{i=1}^{n} p_i (x_i)^{k^*} \geq 0 \qquad \text{for } k = k^*$$

$$a \leq x_i \leq b \qquad \text{for i} = 1,2,\ldots,n$$

$$x_i \geq x_{i-1} \qquad \text{for i} = 2,3,\ldots,n$$

$$p_i \geq 0 \qquad \text{for i} = 1,2,\ldots,n$$

$$\sum_{i=1}^{n} p_i = 1$$

where $k^*$ is a high-order value of $k$ (e.g. $k^*=4$)

In words, equation B.1 seeks to minimize the difference between the true value of a high moment ($k^*$) of a distribution of a continuous random variable, $x$, and a calculated value of the same order of moment from a discrete approximation involving $n$ mass points ($x_1,x_2,\ldots x_n$) occurring with probabilities ($p_1,p_2,\ldots p_n$). The minimization of this difference is subject to other constraints such as all lower order moments ($k<k^*$) in the continuous distribution being equated to those calculated for the discrete approximation. Values of $x$ that form the set of mass points in the discrete approximation must lie within the domain of $x$ in the continuous distribution. Each mass point should be unique and the sum of probabilities of occurrence of the mass points should be unity. In some circumstances, additional constraints can be imposed to reflect special characteristics of the problem such as requirements for symmetry or constraints to reflect particular probability states or mass points.

Gaussian quadrature and this non-linear programming method have the same objective, namely finding $n$ pairs of $x_i$ and $p_i$ such that the moments calculated for the set of $x_i$ and $p_i$ equate to the moments of the continuous distribution. Both methods are clearly preferred over the traditional methods, particularly for small numbers of $(x_i, p_i)$ pairs.

To formulate and solve an approximation problem as a non-linear programming problem is fairly simple. Most spreadsheet packages incorporate non-linear programming algorithms that easily accommodate small problems such as these approximation problems. The application of either Gaussian quadrature or the non-linear programming method both require information regarding the true values of moments of the distribution being approximated. For the more commonly applied distributions (e.g. normal) such information is available from statistical texts and for other distributions values of moments can be generated analytically in spreadsheet or mathematics library software.

The Gaussian quadrature and non-linear programming methods can be extended to various univariate and multivariate distributions.

Consider the example of continuous price distributions for wheat (x) and wool(y) of a certain micron class when marketing schemes are absent. Assume these continuous price distributions are to be approximated by five equally probable price states and that the approximation is required to be accurate to the third moment. The non-linear programming formulation of this problem is:

(B.2) Minimize $\int_{-\infty}^{\infty} x^{k^*} f(x)dx - \sum_{i=1}^{5} f(x_i)x_i^{k^*}$ for $k^*=3$

subject to:

$$\int_{-\infty}^{\infty} x^{k} f(x)dx - \sum_{i=1}^{5} f(x_i)x_i^{k} = 0 \text{ for } k<k^*$$

$$\int_{-\infty}^{\infty} y^{k} f(y)dy - \sum_{i=1}^{5} f(y_i)y_i^{k} = 0 \text{ for } k \le k^*$$

$$\int_{-\infty}^{\infty} y^{k^*} f(y)dx - \sum_{i=1}^{5} f(y_i)y_i^{k^*} \ge 0$$

$$\int_{-\infty}^{\infty} xyf(x,y)dxdy - \int_{-\infty}^{\infty} xf(x)dx.\int_{-\infty}^{\infty} yf(y)dy = \sum_{i=1}^{5} x_i y_i f(x_i, y_i) - \sum_{i=1}^{5} x_i f(x_i).\sum_{i=1}^{5} y_i f(y_i)$$

$$\sum_{i=1}^{5} f(y_i) = 1$$

$$\sum_{i=1}^{5} f(x_i) = 1$$

$f(x_i) \ge 0.01$ for i=1,2,....5

$f(x_i) = f(y_i)$ for i=1,2,....5

In effect this formulation requires that a sample of five points be generated with each point having an equal probability of occurrence. Further, the means and variances as calculated from these sample points should equate to the known means and variances in the continuous distributions. Also the covariance derived from the sample should equate to that known for the bivariate continuous distribution.

To derive price states for the continuous price distributions for wheat and wool classes in

Table 1 involved sequential use of the formulation as described above, with some additional constraints. First the wheat and 20 micron wool price states were generated. Then the price states for the other wool types were found after constraining model solutions to include the known wheat price states. Wool price states for wools of greater micron were also constrained to levels less than the wool prices of the 20 micron wool. These price level constraints were introduced to reflect the known historical price relativities whereby the lower the micron the higher the price. These price relativities, for example, are reflected in the expected prices for each wool grade in Table 1. The optimal set of price states found by the procedures as outlined above is given in Table 2.

The means, variances and covariances for the discrete prices exactly equate to those given in Table 1. Hence, the discrete distributions involving 5 price states are very accurate approximations of the continuous price distributions for wheat and wool. For the distributions affected by marketing schemes the inclusion of price constraints in the system of equations specified above allows points of truncation to be exactly identified and again the means, variances and covariances for the discrete prices exactly equate to those for the winsorised distributions given in Table 1.