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THE USE OF A DECISION MAKER'S UTILITY FUNCTION IN A LINEAR PROGRAMMING ANALYSIS OF AGRICULTURAL POLICY*

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A decision theoretic approach to agricultural policy decision making is examined to discover whether a utility function of an Australian Wool Corporation decision maker can be established and, if so, whether this can be used to improve the policy analysing performance of an agricultural sector linear programming model. After discussing the theoretical requirements of the utility function elicitation and the elicitation procedures, the characteristics of the resulting functions are examined. A means for its inclusion in a linear programming framework is described and some analysis of policy is carried out. The general conclusions are that the relevance of the agricultural sector analysis is enhanced by the use of such a utility function.

Introduction

The purpose of the research reported in this paper was to examine one method of enhancing the relevance of a mathematical programming model designed for policy analysis. An Aggregative Programming Model of Australian Agriculture (APMAA) was developed at the University of New England between 1972 and 1976 (Monypenny 1975; Monypenny and Walker 1976; Wicks, Mueller and Crellin 1978). This model has been used in the analysis of several policy situations (Wicks, Parton and Beesley 1977; Wicks and Dillon 1978). However, one problem with such a model is that it has the attributes of a partial equilibrium model in which fixed instrumental variables are model inputs and the consequences or values of target variables are observed as the solution. The difficulty with this approach is that policy decision makers are usually interested in specific levels of the target variables rather than specific levels of the instruments, and there is no guarantee in the type of analysis which fixes the instrumental variables that appropriate levels of the targets will be observed. This is a problem particularly relevant to the large-scale programming type of analysis in which a major constraint is the limited number of model runs possible.

Tinbergen (1966) is the principal exponent of the reverse approach to economic policy analysis in which the target variables are set at desired levels and the instrumental variables are varied until the targets are achieved as closely as possible. Such an approach would, if possible in the programming framework, overcome the multiple-run problem which is symptomatic of the fixed instrumental variables approach. This is the overall problem examined in this paper. The analysis was carried out in the context of the inventory policies of the Australian Wool Corporation (A.W.C.).

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Multiattribute Utility Theory

Instead of attempting to define fixed levels of the target variables, it was decided to try to obtain a formulation of the preferences of a member of the policy making authority in question. By optimising this preference function it was anticipated that it would be possible to obtain a result which would come as close as possible to the desired target, and which would indicate the type of trade-offs involved in the decision making process. Thus, an indirect and approximate assessment of the preferred level of target variables would be obtained.

The modest objective of the study was to examine the possibility of improving the relevance of information provided for policy decision making purposes. Hence, there is no discussion about the effects on measures of economic welfare, such as allocative efficiency, of implementing policies which result from optimisation of a policy decision maker's objective function. Interesting as this topic appears to be, it is not considered because its complexity causes it to be beyond the scope of the present study.

MacCrimmon (1973) describes 19 multiattribute decision methods, classified into the four broad groups of: weighting methods, sequential elimination methods, mathematical programming methods and spatial proximity methods. Dillon and Perry (1977) compare these different decision methods and show that weighting methods based on multiattribute utility theory (MAUT) are the most comprehensive, incorporating the decision maker's attitudes to both multiple objectives and uncertainty.

MAUT has been applied to decision problems in various fields. These include airport investment (Keeney 1973*b*; de Neufville and Keeney 1974), water resources planning (Wood 1976; Keeney and Wood 1977), research and development planning (Keefer 1977), medical decisions (Giauque and Peebles 1976; Krischer 1976), energy and environmental management (Buehring, Foell and Keeney 1976), siting of nuclear power stations (Keeney and Nair 1977), management of a salmon fishery (Keeney 1976) and many others. The strong similarities between these problems and decision making in the context of A.W.C. inventory policy suggested that the use of a multiplicative multiattribute utility model (Keeney and Raiffa 1976, pp. 288-92) was appropriate. In addition, the use of such a model was supported by its relative simplicity combined with its ability to capture and highlight the relevant details of a decision problem.

The basic notion of MAUT is that an action by a decision maker usually produces value effects in several dimensions. The procedure is to decompose the result of the action into its component value effects in order to discover those values one component at a time. Then, using a suitable aggregation rule, the values are summed across the dimensions. This provides an overall utility assessment of the original action. MAUT is primarily based on the independence of attributes. The three conditions of value independence, utility independence and preferential independence are relevant (Keeney 1973*a*).

In order to establish a multiplicative model it is theoretically necessary to show at least that conditions equivalent to mutual utility independence between attributes are sustained (Keeney and Raiffa 1976, p. 292). Tests for utility independence were therefore included in the formal elicitation described below. If the utility independence conditions are fulfilled, then the procedure is to establish, through the elicitation, separate utility functions $U_i(x_i)$, scaled from zero to one, for each attribute. Having separated the attributes and established a utility function for each of them, it is necessary to recombine them to form an overall utility function. The method of recombination for the multiplicative model is:

$$(1) \qquad 1 + KU(x_1,x_2,\ldots,x_n) = \prod_{i=1}^{n} (1 + Kk_iU_i(x_i)),$$

where U and U_i are scaled from zero to one, and K and k_i are scaling constants. Note that if $\Sigma_i k_i = 1$, then the model is additive. Otherwise it is multiplicative. By discovering appropriate values of these scaling factors during the elicitation, the procedure for recombining the single-attribute utility functions is found.

Elicitation of a Multiattribute Utility Function

A preliminary step completed before commencing the formal elicitation was to structure the problem and determine the most appropriate attributes. The method of generating attributes is initially to outline broad objectives. By breaking down such broad objectives into a representative set of measurable components, a set of attributes is arrived at. There are numerous ways to decompose given objectives into attributes, and the further the decomposition is carried, the more formal the analysis becomes.

A general decision hierarchy showing A.W.C. inventory policy in the overall policy context is shown in Figure 1. The highest level objectives are the social, political and economic aims of the Australian Government. These are pursued through agencies such as the A.W.C. which purport to act on the Government's behalf. The A.W.C. uses a number of policies to effect its objectives, one of which is its stockholding policy. Only the attributes $a_1, \ldots, a_n$ of Figure 1, which relate to the A.W.C. inventory policy, are taken into account in the subsequent analysis.

During preliminary consultation with a designated member (henceforward termed the 'decision maker') of the Economics Department of the A.W.C., eight distinct attributes were considered. It seemed that the Corporation's inventory policy could best be described in terms of the three attributes: indicator price level, level of wool inventory, and number of times that the floor price is changed in a given period. The initial interview confirmed that only the first two of these were of paramount importance, and therefore the third was not considered further in the formal elicitation.

The two attributes which were evaluated are distinct in that in an *ex ante* appraisal any combination of levels of them is possible. However, as was expected, preliminary questioning revealed that the utility independence condition was violated for these two attributes.

In this situation, Keeney and Raiffa (1976, p. 256) suggest four alternative approaches to overcome the dependence problem. The method chosen was direct assessment of a two-attribute utility function. This comprised acquisition of the utilities of a number of consequences

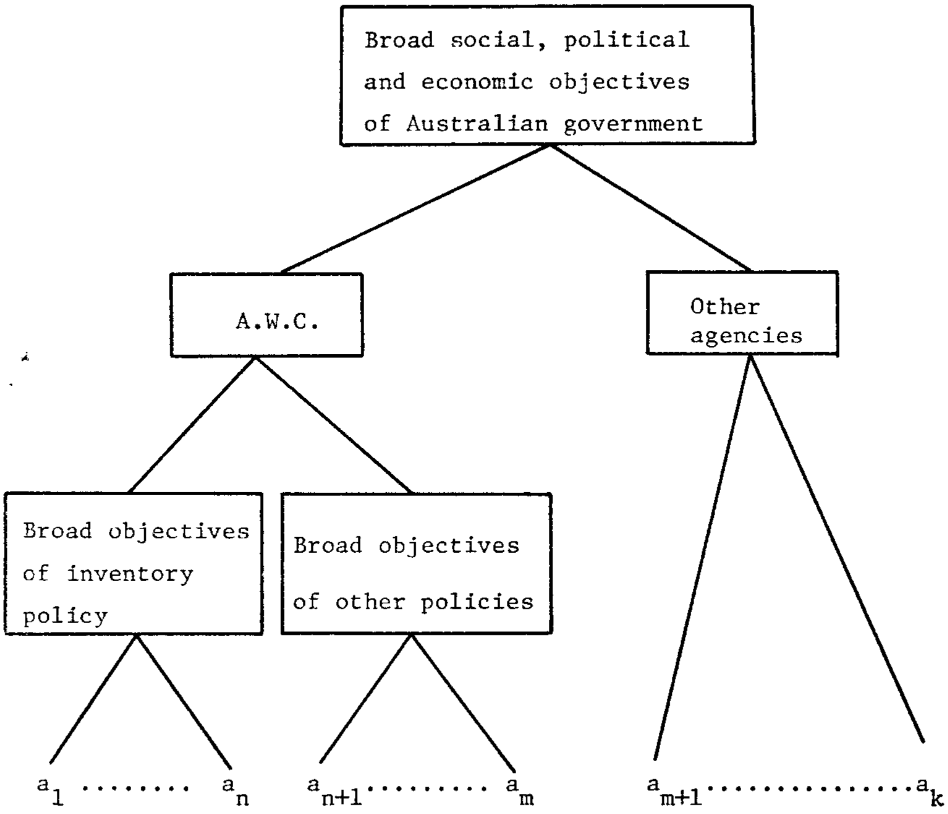

FIGURE 1—One hierarchy showing the relationship between the attributes of the wool stockholding policy and overall objectives of the Australian Government.

involving the two attributes and then the use of a polynomial curve fitting technique to obtain an overall utility surface. Twenty consequences for the coming season, each involving indicator price and inventory level, were evaluated for each of four beginning season price levels. Thus, eighty points on a utility surface, each characterised by an initial price level, a price for the coming season, and an inventory level, were obtained. These were introduced into the model:

$$U = f(a_1,a_2,a_3), \qquad (2)$$

where a_1 is the initial price level, a_2 is the change in price level for the coming season and a_3 is the inventory level.

This model provided a preliminary estimate of the required utility function. In order to improve the function, the decision maker was asked to observe the ranking by the model of 50 alternative outcomes and to determine whether he considered the ranking in need of adjustment. The process was also designed to provide a consistency check and to pressure the decision maker into thinking deeply about the utility valuation implied by the alternatives. This iterative procedure between model and decision maker could have been extended further, but it was considered that a satisfactory correspondence had been obtained, at least for cases involving prices less than 440c/kg, using the function:

$$\begin{array}{llll}
(3)\quad U = & -2.821 + 0.018a_1 & + \ 0.030a_2 & + \ 0.222a_3 \\
 & (0.544)\,(0.003) & (0.002) & (0.104) \\
 & -(2.325\times 10^{-5})a_1^2 & -(4.636\times 10^{-5})a_2^2 & - \ 0.185a_3^2 \\
 & (3.640\times 10^{-6}) & (2.360\times 10^{-6}) & (0.059) \\
 & -(7.635\times 10^{-5})a_1a_2 & +(6.551\times 10^{-4})a_2a_3 & \\
 & (5.041\times 10^{-6}) & (2.069\times 10^{-4}) & \\
\bar{R}^2 = 0.872 & & &
\end{array}$$

where the variables are defined in the same way as for equation (2), and the figures in parentheses are standard errors.

Some Characteristics of the Function

The elicited utility function portrays several interesting, and seemingly logical features. If the focus is placed on the inventory attribute, then an optimal inventory level (at least from the point of view of the decision maker) can be determined, given an expected future price movement. In general, the higher is the expected upward price movement the higher the preferred level of inventory. With no expected price movement, the optimal inventory level seems to be about 0.60 million bales. With a price increase of 50c/kg expected, a 0.69 million bale inventory becomes optimal.

In addition, if the price change attribute is highlighted, whilst ignoring the inventory implications, then an optimal price change can be arrived at as shown in Table 1. This requires the specification of a constant inventory level and a commencing price. Again the outcomes seem consistent because, for example, a higher preferred price level is associated with a higher level of available inventory.

TABLE 1

Optimal Price Changes Given Particular Levels of Commencing Price and Inventory (c/kg clean)

Commencing price	300	350	400	450	500
Optimal price change given a 1.0 million bale inventory	+79	+38	—3	—44	—85
Final price	379	388	397	406	415
Optimal price change given a 0.5 million bale inventory	+76	+35	—7	—48	—89
Final price	376	385	393	402	411

It should be noted that none of the outcomes shown in Table 1, such as price 388c/kg and inventory 1 million bales, is necessarily attainable. The attainable states are determined in the wool market. The use of a model of this market which permits definition of attainable states and enables an optimal choice between them is now described.

Modelling the 1975/76 Season

It was decided to attempt to simulate the 1975/76 season using the utility function in conjunction with the APMAA model. It was expected that the utility function would operate satisfactorily given that prices during the season did not approach 400c/kg. The APMAA model was used to represent the autonomous actions of other market participants, whilst the utility function was optimised to achieve the desired outcome for the A.W.C. decision maker in terms of level of net stock release or intake. A simplified representation of the core of this LP model is shown in Figure 2.

The selling activities and wool market constraint together represent a linearly segmented demand structure, the objective function entries for these activities being relevant areas below demand functions. The transfer activities move wool to the wool market from a set of production activities which represent the agricultural production sector. The objective function entries for these activities are variable costs of transfer and production, respectively. WCS and WCB are activities representing transfer of wool by the A.W.C. to and from the market, respectively. The part of the model so far described is based on conditions of perfect competition.

The utility activities and related constraints represent A.W.C. actions in the wool market. The s_x values denote a level of stock release, and the q_y values denote the market price achieved (with price and quantity linearly related). Each combination of s_x and q_y has an associated utility value, u_{xy}, with $0 \leqslant u_{xy} \leqslant 1$. Hence, this part of the model maps out feasible combinations of stock release and market price, and registers a utility value associated with them.

The way in which the overall model is run is to parametise the right-hand side of the utility optimising constraint between 0 and 1. The last feasible solution is the utility maximising outcome. By means of this parametric procedure, the policy objective is optimised whilst throughout maintaining the behavioural maximand which ensures a competitive equilibrium.

Using this model to analyse the 1975/76 season, the results in Table 2 were obtained. The first column of figures in Table 2 shows the actual outcome during the 1975/76 season, when a net release of wool totalling 26.1 kt (clean equivalent) was made by the A.W.C. In the second column, the model equilibrium, when the same amount of inventory was released, is shown. No comparison between the actual position and the equilibrium solutions is necessary. The comparison that is relevant is that between columns 2, 3 and 4.

The utility associated with the column 2 configuration, which includes the stock release policy at the level established by the A.W.C. in 1975/76, is less than that of the optimum configuration of column 3. What is implied by these results is that, from the point of view of the designated decision maker, the A.W.C. policy decision on the net amount of wool inventory to release could have been improved by selling about half the quantity of wool that it did in 1975/76. However, as noted below, several provisos need to be taken into account. In column 4, the equilibrium position without any intervention by the A.W.C. is shown.

Constraints	Activities						RHS
	Selling activities	Transfer activities	WCS	WCB	Utility activities	Production activities	
Objective	$c_1 \ldots$	$\ldots$	$\ldots$	c_{m+2}		$c_k \ldots c_n$	Maximise
Wool market	$q_1 \ldots q_i$	$-1 \ldots -1$	-1	1			$= 0$
Production Constraints		1				p_k	$\leqslant 0$
		$\cdot$				$\cdot$	$\cdot$
		$\cdot$				$\cdot$	$\cdot$
		$\cdot$				$\cdot$	$\cdot$
		1				p_n	$\leqslant 0$
Policy variable			1	-1	$s_1 \ldots s_j \; s_1 \ldots s_j \ldots \ldots s_1 \ldots s_j$		$= 0$
Price		$-1 \ldots -1$	-1	1	$q_1 \ldots q_1 \; q_2 \ldots q_2 \ldots \ldots q_i \ldots q_i$		$= 0$
Convexity					$1 \ldots 1 \; 1 \ldots 1 \ldots \ldots 1 \ldots 1$		$\leqslant 1$
Utility optimising					$u_{11} \ldots u_{1j} \; u_{21} \ldots u_{2j} \ldots \ldots u_{i1} \ldots u_{ij}$		Parametric

FIGURE 2—Parametric LP structure of the utility optimisation.

TABLE 2

Configurations for 1975/76 Given Various Levels of Net Release of Inventory by the A.W.C.[a]

	Actual outcome (1)	Single year equilibrium position of actual policy (2)	Optimum equilibrium position (3)	Equilibrium with zero stock release (4)
End of season inventory level (million bales)	1.315	1.315	1.474	1.605
Equilibrium price[b] (c/kg clean)	262[c]	291	298	303
Net stock release (kt clean)	26.1	26.1	11.8	0.0
Average price previous season[b] (c/kg clean)	256	256	256	256
Utility	0.327	0.589	0.598	0.591

[a] The results in this table show a different optimal configuration from that presented in Parton (1979). This results from a computational error in the original analysis which has now been corrected.
[b] This refers to 21 μm wool.
[c] Average price for season.

Several limitations to these results should be recognised. They may account for some of the differences between the model optimum and the policy actually pursued. It must be accepted that the model, like all models, has many misspecifications and considerable measurement error. The A.W.C. decision makers operate in an uncertain environment, whereas the model outlined here disregards such uncertainty. In addition, during the 1975/76 season the A.W.C. was presumably obtaining forecast information on wool supplies and prices for the following season. Hence, the A.W.C. decision making procedure is a dynamic, multiperiod process in an uncertain environment, whereas it has here been modelled as a static, single-year equilibrium model. These simplifying assumptions are partially relaxed in the next section to obtain a more reasonable *ex ante* analysis.

Uncertainty and Multiperiod Aspects

The objective of incorporating uncertainty was to obtain an approximately optimal plan for the 12 months from the commencement of the 1975/76 season, based on probabilistic information available at that time and pertaining to the following 24 months. An overview of the methodology to achieve this is described in this section. The 1975/76 season is referred to as year 1, and the following season as year 2.

The optimal A.W.C. plan was defined as that which achieved the highest expected level of the elicited utility function over the two years under consideration. It was assumed that the utility function itself was unchanged over this period. In addition, a method of aggregating utilities from the two time periods was required. There is debate in the literature about whether, and the method by which, future utilities should be discounted (Ramsey 1928; Koopmans 1960; Lancaster 1963;

Koopmans, Diamond and Williamson 1964; Meyer 1976). It was impossible to resolve this controversy in the present analysis and, consequently, utilities from year 1 were merely summed with utilities from year 2.

The components of the A.W.C. planning problem can be examined by use of Figure 3 which shows demand and supply curves for Australian wool. There is an aggregate supply curve for wool from Australian producers which is subject to stochastic effects, principally the weather. It takes position S_k with probability ρ_k. In addition, the demand curve for Australian wool is also subject to episodic shifts, and takes position D_j with probability ρ_j. The probabilities ρ_k and ρ_j are assumed to be independent of each other and $\rho_j \rho_k$ $(= \rho_{jk})$ is the probability that the demand curve takes the position D_j whilst the supply curve takes the position S_k.

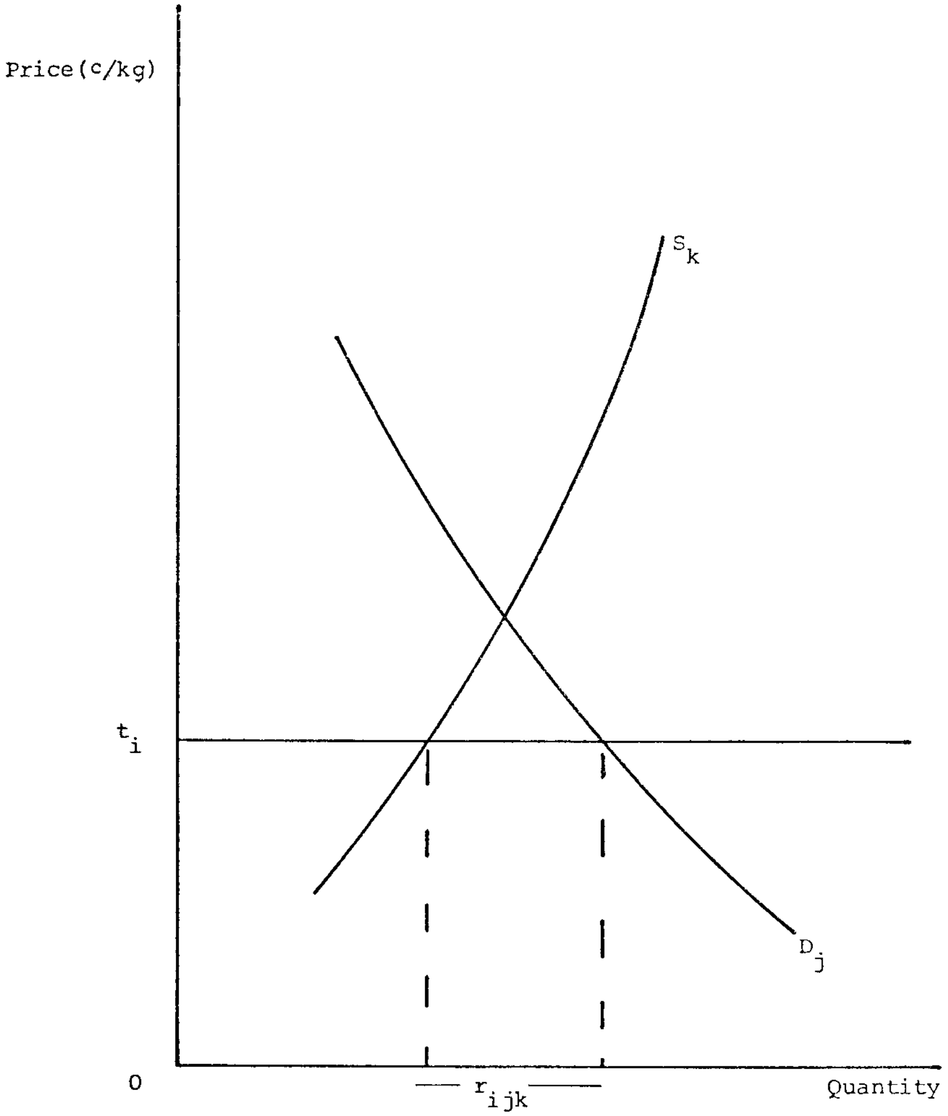

FIGURE 3—Components of the A.W.C. buffer stock planning problem.

It was assumed that the A.W.C. is interested in achieving a particular market price for wool of t_i in year i. The expected utility in a specific year associated with a particular t_i is:

$$(4) \qquad EU(t_i) = \Sigma_j \Sigma_k EU(P_i, r_{ijk}) \rho_{jk}$$

where P_i is the outcome price and r_{ijk} is the level of the A.W.C. stock release variable when price P_i is achieved, and the demand and supply functions take positions D_j and S_k, respectively. The process of discovering the optimal plan is the same as finding the t_i which has the highest expected utility, except that the summation in equation (4) is extended to cover the number of years of the planning horizon.

Uncertainty on the demand side was introduced through probabilistic demand functions. Five possible positions of the demand curve for wool for each of the two seasons under study were estimated, together with their associated probability of occurrence. The demand curve positions should have been derived from the expectations of the decision maker. However, it was impossible to obtain an idea of his 1975/76 pre-season expectations late in 1977 when the elicitation took place. The procedure adopted was to estimate expected demand curve locations for 1975/76 and 1976/77 from end of season futures prices quoted at the start of 1975/76.

On the supply side, it was assumed that conditions of certainty prevailed for the first year, and that yield variability affected wool production in the second. A deterministic model of supply for the first year seemed applicable because the A.W.C. is able to estimate the supply for the coming season fairly accurately. This is partly because a large part of the rainfall that affects yield during a season falls before the season starts. Therefore, stochastic supply effects were assumed to be limited to the second year.

Three possible wool yields were considered for the second year. These were termed high, medium and low yields, and were estimated from 19 annual yields prior to 1975/76. A particular yield was introduced directly into the LP model by assuming that wool yields on all representative farms were affected similarly. Such an assumption would be unreasonable if a disaggregated analysis were being performed. It would require more detailed, locationally specific, yield variability data. However, for the purposes of the present analysis, this assumption seemed satisfactory.

The treatment of uncertainty in demand and supply meant that five runs of a model similar to that of Figure 2, differing in their demand structure, were necessary for evaluation of year 1, and 15 model runs, each characterised by a given yield and demand structure, were required for year 2.

As explained above, the purpose of the analysis was to find an optimal price, t_i, which is the policy target. In the LP context described here, only an approximation to this optimal target price was achieved. This was because only 10 discrete target prices were defined and evaluated for each year and, hence, only 100 of the infinite number of possible two-year plans were considered.

There are numerous ways to summarise the results. Those results reported in Table 3 seem to be the most relevant. The expected utilities, in both years, of a year 1 decision are shown. When year 1 is treated separately, a target price of 310c/kg gives the highest expected utility. Outcomes in the second year were shown to be quite insensitive to the year 1 decision, but the best year 1 decision in terms of year 2 expected utilities is 275c/kg. Overall, the optimal target price in year 1 is 285c/kg. Hence, there was a trade-off between utilities expected in each year.

TABLE 3

Expected Utilities Associated with Various Target Prices

Year 1 target price (t_i)	Expected utility year 1	Expected utility of preferred year 2 decision	Total expected utility
250	0.545	0.742	1.287
260	0.608	0.750	1.358
270	0.658	0.750	1.408
275	0.673	0.752	1.425
280	0.689	0.751	1.440
285	0.699	0.750	1.449
290	0.698	0.748	1.446
295	0.695	0.744	1.439
300	0.701	0.739	1.440
310	0.701	0.726	1.427

It was observed during the utility function elicitation process that a price objective was more dominant, from the A.W.C. decision maker's viewpoint, than an inventory objective, at least in the price ranges and inventory levels considered here. This dominance was again portrayed in the model results of the current analysis. When each year is observed separately, a relatively high price in that year leads to high expected utilities. For year 1 this is seen directly from the results in Table 3, because a high target price for that year yields a high expected utility. For year 2, it was discovered that the preferred choice at all the year 2 decision nodes was either the highest or second highest price. A point of significance flowing from these observations is that a single-year modelling process leads to policy prescriptions involving rather unstable prices. By considering a simple two-year dynamic process, the highest expected utility is associated with a seemingly more stable price outcome. Given that the desirability of such an outcome is implicit in A.W.C. objectives, a two-year process appears to model the Corporation's decision making framework better than a single-year process.

Conclusions

A multiattribute utility formulation of an A.W.C. decision maker's preferences was established and used in conjunction with a large-scale LP model of the agricultural sector. The initial hypothesis was that this would confine the analysis to areas of policy-maker interest and, hence, reduce the number of runs of such a model required to produce a relevant policy analysis. The results achieved tend to support the hypothesis. A single parametric run of a static single-year model which incorporated optimisation of the policy objective by varying the instruments was used to replace many runs of the alternative fixed instrument version. In addition, it was possible to extend the analysis to include multiperiod and uncertainty effects. Such an extension, even if possible with the fixed instrument version of the model, would have been extremely cumbersome.

Furthermore, several additional benefits of the initial investment in establishing a utility function were observed. Not only was it possible to define an optimal policy from the point of view of the decision maker, but also much more information was available about suboptimal positions. Moreover, even from the commencement of the modelling process, the model builder and decision maker benefited from a much clearer impression of the policy environment and its relationship to the model.

The latter part of the research consisted of a comparison between analyses including and excluding uncertainty and multiperiod aspects. In theory, the inclusion of such aspects should produce a much sounder analysis because it represents an attempt to incorporate in a more realistic fashion the available information. The model results obtained tended to lend some support to this notion.

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