Australian Journal of Agricultural Economics, Vol. 27, No. 1 (April 1983), pp. 44-72

AN OPTIMAL-CONTROL APPROACH TO STABILISING AUSTRALIAN WOOL PRICES*

MIKE HINCHY and PHIL SIMMONS
Bureau of Agricultural Economics, Canberra, 2601.

In this paper, some aspects of the application of optimal-control techniques to wool industry price stabilisation are considered. It is not intended to provide a blueprint for the immediate adoption of optimal-control techniques in the management of wool price stablisation. Rather, the contribution is to the developmental and evaluative process involved in considering these techniques. A new econometric model of wool price and supply is also presented, since none of the existing models satisfied the requirements of the study.

Introduction

In this paper, the possibility of applying optimal-control techniques to stabilising Australian wool prices is considered. Given the nature of the problem, it is helpful to begin by discussing the motivation for the paper before turning to an outline of its contents.

Motivation

The theoretical advantages of applying optimal-control techniques to economic stabilisation problems have long been recognised. A vast number of papers illustrating the use of the technique have been published and a journal (*Journal of Economic Dynamics and Control*) specifically devoted to the topic is now published. However, progress toward realising the theoretical advantages of the technique has been quite slow. At the time of writing, the authors do not know of any stabilisation scheme actually run using optimal-control methods.

The major obstacles usually cited as delaying the adoption of the techniques are:

(a) the need to use an explicit function representing policy makers' objectives;
(b) the need to use an explicit econometric model (or group of models) in deriving optimal-control policies; and
(c) the problem of devising a suitable institutional structure in which optimal-control policies can be derived and implemented.

There is perhaps a fourth difficulty of a more technical nature. In spite of the growing sophistication of optimal-control algorithms, no single algorithm may be available that can capture all of the elements considered to be relevant to a particular problem.

A further difficulty that arises, given problems (a) to (c), is that it is not easy to demonstrate by historical simulations that policy makers would have achieved a 'preferred outcome' if they had adopted an optimal-control approach. It is always possible to object that the wrong objective function was used and/or the wrong model was used and/or the assumed institutional structure was inappropriate. Of course, if the implicit

* The authors would like to thank many colleagues at the BAE and the anonymous referees for helpful comments on earlier versions of this paper. Naturally, the usual caveat applies.

welfare function and model used by policy makers could be made explicit, then there would be no difficulty in demonstrating the superiority, or at least non-inferiority, of an optimal-control policy. An optimal-control policy is defined by the property that no other policy can yield a preferred value for the welfare function. The only question to consider would be whether the gain from adopting optimal-control policies exceeded the costs of establishing and maintaining an institutional structure in which such policies could be derived and implemented.

The authors believe that none of the above problems is insurmountable and that eventually stabilisation schemes will be run using optimal-control methods. However, they also believe that the movement from existing decision-making methods to optimal-control techniques will not be made in a single jump but rather by means of a long development process. An important step in this movement toward improved decision making is to attempt to formulate a stabilisation problem in an optimal-control framework. This has the advantage of making explicit all of the components of the problem and emphasising its dynamic nature whereby current policy actions will influence future policy options. Such a formalisation of the problem makes explicit the points of contention and may provide the policy makers with a better appreciation of the nature of the problem. While this may not result in the immediate adoption of optimal-control techniques, it may stimulate research into problems which must be considered before such techniques can be applied confidently.

Content

Wool price stabilisation provides a case study for the possible application of optimal-control techniques and we build upon the pioneering work of Dalton (1976). Government authorities have bought and sold wool with the aim of modifying Australian auction prices since 1970. The scheme currently in operation consists of a minimum reserve price (MRP) and a flexible reserve price (FRP). The MRP allows wool to be bought to provide a guaranteed minimum price. It is now set for a period of one year, subject to the condition that it will not be less in the next year. The FRP is varied more frequently and was introduced to allow wool to be bought at a given centre if bids were low relative to the rest of the market, or if the entire market was affected by some short-term disturbance.

It is a matter of definition whether or not the MRP scheme is described as a price stabilisation scheme. The scheme clearly can reduce downward movements in price but contains no formal rule for the sale of accumulated stock. In practice, it appears that most stocks have been sold when prices are high relative to the ruling MRP. Thus, it is possible that the operation of the scheme may have reduced both upward and downward movements in price. The Australian Wool Corporation (AWC) believes that the scheme has reduced the variability of prices as indicated by coefficients of variation (Ward 1978).

In this paper, the possibility of developing the scheme into an explicit price stabilisation scheme is considered. As mentioned above, it is believed that a number of advantages stem from such an attempt to formalise the decision problem. However, an attempt is made to go further and estimate the potential gain from adopting an optimal-control approach. This is done by comparing the performance of the Reserve Price Scheme with that of the optimal-control approach over the period 1970 through 1979 assuming optimal-control is applied in a particular way, given a particular objective function and econometric model. It is immediately conceded that such an exercise is subject to all of the problems mentioned above. Furthermore, in the present application, the results reflect the effects not only of improved decision making but also more accurate market information. In spite of all the qualifications that must be attached to the interpretation of the results, the authors believe that they lend support to the view that there may be significant gains from improved decision making. Hence, further research on the problem may be quite fruitful.

Problem structure

The following steps are involved in setting up the wool price stabilisation problem as an optimal-control problem. First, a welfare function is needed to express the aims of the policy authorities. Second, a control variable(s) must be selected which can be set by the authorities to influence target variables. Third, a decision must be made as to how frequently the control variable should be varied. Fourth, an econometric model is required which expresses the relationship among control and target variables. Finally, a control algorithm is needed to minimise (maximise) the welfare function subject to the constraints imposed by the econometric model.

Ideally, the choice of functional form for the objective function and econometric model should be governed by the requirements of the problem. However, at an early stage in the present study it was decided to use a parameter-uncertainty optimal-control algorithm which minimises a quadratic welfare function subject to a linear econometric model. Thus, the choice of an algorithm, given the costs involved in programming, constrained the choice of functional form for the objective function and econometric model. The time interval of the model was governed by the decision to use a quarterly decision period for the optimal control analysis.

Each of the steps involved in setting up the wool price stabilisation problem as an optimal-control problem is discussed in the subsequent sections of the paper. An attempt is then made to compare the forecast performance of the optimal-control approach with that of the Reserve Price Scheme over the period 1970 through 1979. Given that the development of the econometric model was one of the largest and most self-contained parts of the study, this is discussed first before turning to the other elements of the control problem.

The Econometric Model

The choice of a quarterly decision period, the restriction that the econometric model be linear and the need to obtain the covariance matrix of coefficients for the parameter-uncertainty algorithm resulted in a new econometric model being developed for this study since no available model satisfied these requirements. It was considered that supply effects should be included in the analysis because they are a potentially important part of the problem. Current net purchases by the AWC will affect current price and thus future supply and, hence, future price. Thus, supply effects add a dynamic dimension to the current decision-making problem and greatly increase its complexity. The dynamic nature of the problem is the reason for believing that optimal-control analysis offers major advantages for decision making.

The model was designed primarily for use in an optimal-control context with emphasis on tracking and forecasting performance. The issue of the ease of forecasting exogenous variables was also taken into account in model design. While the model is derived from what the authors believe to be a number of plausible assumptions about the operation of the wool industry, the primary aim was not to provide a structural explanation of the wool industry. If this had been the case, a number of issues would have been pursued in greater depth and the restrictive linearity assumption, which was essential for the optimal-control work, would have been abandoned.

A recursive two-equation model was developed. It determines price and supply (receivals into store) in the Australian wool market and was estimated using ordinary least squares over the period 1968 (II) to 1979 (IV). The preferred estimates of the structural equations in the model are set out below;

$$
\begin{aligned}
P_t = {} & \underset{(3.169)}{238.2} \; \underset{(-2.202)}{-47.608SD_1} \; \underset{(-3.094)}{-78.0950SD_2} \; \underset{(-2.399)}{-28.593SD_3} \\
& \underset{(-3.072)}{-0.4788(S_t - NP_t)} \; \underset{(13.031)}{+0.7954P_{t-1}} \; \underset{(4.339)}{+2.4783D_t} \; \underset{(-3.196)}{-1.4438E_t}
\end{aligned}
$$

$R^2 = 0.93 \quad DW = 1.87$; and

$$
\begin{aligned}
S_t = {} & \underset{(17.8)}{239.5} \; \underset{(-21.44)}{-145.820SD_1} \; \underset{(-22.26)}{-175.355SD_2} \; \underset{(7.55)}{-50.352SD_3} \\
& \underset{(7.639)}{+1.1830WMA_t} \; \underset{(-7.366)}{-0.6701GMA_t} \; \underset{(-7.096)}{-2.4241C_{t-4}}
\end{aligned}
$$

$R^2 = 0.96 \; DW = 1.75$,

where P_t = BAE indicator of clean wool prices, c/kg;
S_t = receivals of wool into store, kt greasy;
NP_t = net purchases of wool by AWC, kt;
D_t = BAE diffusion index of economic activity in major wool consuming countries;
E_t = Australian Treasury exchange rate index;
SD_i = 0-1 seasonal dummies for first three quarters of calendar year;
WMA_t = expected price of wool (moving average of past 3 years prices lagged one year), c/kg;
GMA_t = expected price of wheat (distributed lag of past prices), \$/t; and
C_t = award shearing rate, \$/100 sheep.

A full description of the variables and data sources is provided in the Appendix.

Price equation

The price equation in the model is a 'reduced-form' equation derived by considering the interaction between demand and supply. The following arguments underlie the specification of the demand function.

Economic activity. Demand for wool is a derived demand and depends ultimately on the level of consumer demand for woollen products. In common with earlier demand studies for wool (Hussey 1972; Dalton and Taylor 1975), it is assumed that demand varies with the level of economic activity in major wool-using countries which is proxied by the BAE diffusion index.

Price expectations. Since wool is a storable commodity, wool processors have the choice of varying stockpiles of wool as well as purchases of wool. Thus, demand was assumed to be affected by buyers' price expectations. The work of Fisher and Tanner (1978) suggests that the wool market is reasonably information-efficient. Using Fama's (1970) definition of informational efficiency, namely, that current price incorporates all available information about future price movements and evidence that wool prices can be described by a first-order autoregressive process, a lagged price term was used as an approximation of purchasers' price expectations (McKenzie, Philpott and Woods 1969).

Fibre substitution. There are essentially two views on the process of fibre substitution. First, it can be argued (see Powell, Polaseck and Burber 1963) that the long-run equilibrium market share of synthetic fibres is determined primarily by technological factors. Thus, the increasing use of synthetic fibres since the 1920s represents the adoption process for a new product with associated investment in new plant. Once the technologically-determined market share was reached (perhaps in the late 1960s), observed fibre substitution would become less sensitive to movements in the relative prices of competing fibres. The alternative view is that competing fibres are continuously substitutable across the range of possible relative prices and, hence, no variation in responsiveness to relative prices would be observed over time.

Exchange rates. Since the bulk of Australian wool is sold to overseas buyers, exchange rate changes are expected to affect demand. If Australian dollars become cheaper to foreign buyers, demand at auction is expected to strengthen and *vice versa.* A general index of exchange rates was used in preference to a wool trade weighted index, since the latter would have involved problems of aggregation beyond the scope of the present analysis.

Seasonality. The issue of whether there is any seasonality in demand is also of some importance in the context of a quarterly model. There is a strong seasonal pattern in supply, with about two-thirds of the annual clip entering store during the third and fourth quarters of the calendar year. However, no seasonal pattern is evident in prices, which implies that there must be seasonal shifts in demand closely matching the seasonal pattern of auction offerings.

There are two factors which might explain these seasonal shifts in demand. First, there is a seasonal pattern in wool consumption which peaks during the Northern Hemisphere winter. If processors wish to minimise stockholding costs, this seasonal pattern of consumption, given lags for time in transit, might be translated into a seasonal pattern of demand which parallels the seasonal pattern of Australian supply. Second, the storability of wool makes arbitage over time possible, which may create a seasonal pattern of demand matching that of supply and limiting the scope for seasonal variation in price. The interaction between the above two factors could create seasonality in demand.

If the quantity demanded is assumed to be affected by the above variables, together with own price, two further assumptions are required to derive the 'reduced-form' price equation presented above. These are that supply is independent of current price and quantity demanded is equal to quantity supplied. Given these assumptions, price can be expressed as a function of the above demand variables and supply minus net purchases by the AWC. The subtraction of net purchases by the AWC from supply is essential if the assumption of market equilibrium is to be satisfied. If this adjustment were not made, observations of price and quantity during periods of AWC intervention (i.e. buying or selling) would not represent points on the *ex ante* demand curve and a model of market disequilibrium would be appropriate.

For the above assumptions to hold, it is necessary that net purchases by the AWC be independent of current price. It might be argued that this assumption cannot be sustained, given the operation of the Reserve Price Scheme (also see results of Carland 1981, using monthly data). However, an attempt to develop a behavioural model for AWC net purchases failed to reveal any significant linear relationship between AWC net purchases and current price over the estimation period. The addition of a behavioural relationship for net purchases and estimation of the system by two-stage least squares failed to result in any significant changes in coefficients in the price equation.

Supply

The supply of wool was assumed to be a function of expected price, the expected price of production substitutes, costs specific to wool growers (i.e. shearing costs) and weather conditions. Supply was also assumed to shift seasonally, since climatic and biological factors result in the bulk of sheep being shorn during a concentrated period within the year.

Expected price. It was assumed that growers operate over a reasonably long decision horizon, since current decisions on culling rates and flock composition affect long-term production capacity. A simple theory of expectations formation is that growers identify the trend in prices and work on the assumption that the trend will be maintained. As there is evidence of a 3-4 year cycle in wool prices (see below), a 12-quarter moving average of past prices would make a reasonable estimator of trend, tending to smooth any short-term fluctuations. This term was lagged one year, since the number of sheep available to be shorn in a given year depends primarily on decisions made one year earlier.

Expected price of production substitutes. In addition to the return from wool, growers would also need to consider the expected long-run return from production substitutes. The main substitute was expected to be wheat, although the return from lamb may be relevant, while cattle also may be a substitute in some regions. Analogous to the reasoning for own price, a weighted average of past prices might form an appropriate estimator of the expected trend in prices.

Rainfall. Low rainfall may result in poor lambing rates and drought deaths. However, the effects of high rainfall are not as unambiguous.

While high rainfall may result in increased pasture production and, hence, higher wool production, it may also damage wool to the extent that production falls. In using quarterly data, there is the further problem that rain just prior to shearing may result in postponement of shearing and, hence, delivery at later dates than otherwise expected.

Costs. Costs specific to the wool industry were measured by the award shearing rate. Since expected shearing costs will be taken into account in growers' decisions on culling rates and flock composition, this variable was lagged four quarters to serve as a proxy for expected shearing costs.

Estimation results

All of the variables in the price equation were significant and had the expected sign with the exception of the synthetic price variable which was insignificant. This result is consistent with one view of the fibre substitution process mentioned above but, as there are considerable problems in constructing a representative index of synthetic fibre prices, this result should not be taken as decisive.

In the supply equation a number of variables were not significant. Wheat was found to be the only significant production substitute. In approximating the wheat price expectations variable, a number of forms of distributed lags were used, including Almon polynomial and geometric lag structures. However, the most satisfactory results were obtained using a weighting system developed by Freebairn (1975) as described in the Appendix.

In the case of rainfall, as pointed out above, theoretical expectations were ambiguous. A sheep numbers weighted index of rainfall was constructed for the 20 major wool-growing districts. A number of lag structures using this index were tried with different lengths and weighting patterns but none of the results were significant.

System results

The price and supply equations were combined into a system. The coefficient on the 3-year moving-average expected price term in the supply equation was divided by 12 and the resulting coefficient assigned to the relevant lagged price terms. The reduced-form coefficients of the system and their asymptotic standard errors are shown in Table 1. The asymptotic standard errors were calculated from the asymptotic reduced-form covariance matrix and its derivation is discussed below.

Characteristic roots and dynamic multipliers for the system were calculated. The system was just stable, with the dominant root having a modulus of 0.97. The conjugate complex roots contribute cycles of about 3.5 years, 1 year, and 0.5 of a year to the deterministic time paths for the endogenous variables. The 3-4 year cycle was evident in the dynamic multipliers which tend to alternate in sign over that period. This evidence of a 3-4 year cycle is consistent with the spectral results for historical prices reported below.

The delay multiplier for the effect of a change in AWC net purchases on price became negative after a 7-quarter lag. Thus, policy action which may have a stabilising effect in the current period may be de-stabilising in the long run. These long-run dynamic effects are taken into account in deriving optimal-control policies for the current period.

TABLE 1

Reduced-Form Coefficients and Asymptotic Standard Errors

Endogenous variable[a]	Predetermined variable[b]						
	P_{t-1}	$P_{t-4} \ldots P_{t-15}$	CON	SD_1	SD_2	SD_3	NP_t
P_t	0.80	−0.05	123.53	22.21	5.86	−4.48	0.48
	(0.06)	(0.03)	(49.66)	(11.77)	(11.69)	(11.03)	(0.15)
S_t	0.0	0.10	239.50	−145.82	−175.35	−50.35	0.0
	(0.0)	(0.05)	(13.39)	(6.80)	(6.68)	(6.66)	(0.0)
	D_t	E_t	GMA_t	C_{t-4}			
P_t	2.48	−1.44	−0.32	1.16			
	(0.60)	(0.45)	(0.11)	(0.41)			
S_t	0.0	0.0	−0.67	−2.42			
	(0.0)	(0.0)	(0.09)	(0.34)			

[a] P_t = BAE indicator of clean wool prices, c/kg; S_t = receivals of wool into store, kt greasy.

[b] P_{t-i} = lagged value of BAE indicator of clean wool prices, c/kg; CON = constant term; SD_i = seasonal dummies for first three quarters of calendar year; NP_t = net purchases of wool by AWC, kt; D_t = BAE diffusion index of economic activity in major wool consuming countries; E_t = Australian Treasury exchange rate index; GMA_t = expected price of wheat as distributed lag of past prices, \$/t; and C_{t-4} = award shearing rate lagged four periods, \$/100 sheep.

Welfare Function

In this section, three issues relating to the form of the welfare function are discussed. First, the problem of which variables to include in the welfare function is considered. Second, the choice of appropriate target paths for the selected target variables is discussed. Finally, possible errors arising from approximating the welfare function by a quadratic form are discussed.

Choice of variables

No attempt will be made to derive a specific welfare function for the optimal-control problem from broader considerations of producer and consumer welfare. This is an extremely complex topic that is beyond the scope of the present paper. Instead, the aim of stabilising prices was simply taken as given so that wool prices were automatically included in the welfare function. The size of the AWC's stockpile was also included as a proxy for the costs of holding stocks. Many of the other policy aims mentioned in discussions of the Reserve Price Schemes, e.g. supply and income stability (see AWC 1978), may be attained partly through greater price stability. The control results presented later contain information on the effects on some of these other policy aims.

The issue needs to be considered of whether wool prices should be stabilised in local-currency or user-currency terms. It has been suggested that increasing the stability of wool prices relative to competing fibre prices will increase the demand for wool (see Ward 1978). As a result of this possible effect, it has been suggested that prices should be stabilised in terms of user-currencies. However, the belief that more stable prices from stabilisation will increase the demand for wool is not universally shared. Indeed, the counter suggestion has been made that price stabilisation may amplify fluctuations in mill throughput (Watson 1980) and so discourage investment in early processing stages specific to wool, resulting in reduced demand for wool. Moreover, Quiggin (1983) has suggested that it is possible that the long-run effect of stabilising prices is to increase the risk faced by wool users.

If the possibility is granted for the moment that increasing the stability of the price of wool relative to competing fibre prices may increase the demand for wool, it is still not obvious that the authorities would wish to stabilise in user-currency terms only. Increasing price stability in overseas currency terms is likely to reduce price stability in domestic currency terms if exchange rates are variable. Thus, there may be a trade-off for growers between the benefits of increased demand and any benefits they derive from greater price stability. Hence, growers may prefer stabilisation in some weighting of local-currency and user-currency terms.

In view of the conflicting theoretical arguments about the merits of stabilising in user-currency terms and the lack of any empirical evidence on the issue, it was decided to stabilise in local currency terms. However, for the historical period considered in the control runs, stabilising in local currency terms also resulted in increased stability for users, as described below.

Price target. The aim of price stabilisation was taken to mean reducing the amplitude of short-term fluctuations in price without altering its long-term expected value from that which would result in a free-market (i.e. no AWC buying and selling) situation. If increased price stability resulted in increased demand for wool, then it is possible that a higher long-term expected value for price might be incorporated in the price stabilisation aim. Alternatively, if stabilisation reduced the demand for wool, then a lower long-term expected price might be appropriate to the stabilisation aim. However, these problems are not considered here. In order to find what form of price target would be consistent with the price stabilisation aim, the historical record of prices was examined to see if there was any regular pattern of short-term fluctuation.

In Figure 1 is shown the estimated spectrum of the BAE indicator of clean wool prices over the period 1958 through 1978 using quarterly data. First-differencing of this series was adequate to achieve stationarity. The spectrum shows quite a distinct peak corresponding to a cycle of about 3 years in length and no other major peaks.

Since the above series was not long enough to detect a cycle of much more than 3 years in length, the longest available series was examined to see if there were any significant long-term cycles. This series is the estimated average price of Australian greasy wool which is available on an annual basis from 1861-62 through 1978-79. First-differencing of this series did not achieve stationarity and a percentage change transformation was used instead. The graph of the estimated spectrum is shown in Figure 2. There is no evidence of a significant cycle greater than 3 years in length and again a cycle of about 3 years accounts for a significant part of the total variation in the series.

On the basis of the above results, it seems that a 12-quarter moving average of forecast prices might form an appropriate price target. This would tend to smooth a 3-year cycle without affecting the long-term expected value of price.

Stockpile target. The stockpile target should be consistent with one of the aims of price stabilisation, namely, that AWC buying and selling should have no effect on the long-term expected value of price. A possible approach would be to set the stockpile target to zero over the entire control period. This would also be consistent with the aim of minimising stockholding costs. However, to the authors' knowledge, no optimal-control algorithm has been developed yet which can incorporate a direct non-negativity constraint on a target variable. If the stockpile target were to be set at zero, it is possible that the stockpile might become negative during the control period. It was decided to deal with this problem by setting a relatively low constant value for the stockpile target. This value could be interpreted as the level of stocks to be held against the contingency of an unforseen change in price.

The relative weights on the price and stockpile targets were then varied. If the problem of negative stocks still emerged, the results were either discarded as representing infeasible policies or the stockpile target was varied in certain periods to ensure that stocks remained non-negative. Details of these adjustments are reported.

Quadratic approximation

The final issue relating to the welfare function that needs to be considered is the appropriateness of the quadratic approximation. It is certainly possible that the authorities may not wish to assign equal penalty

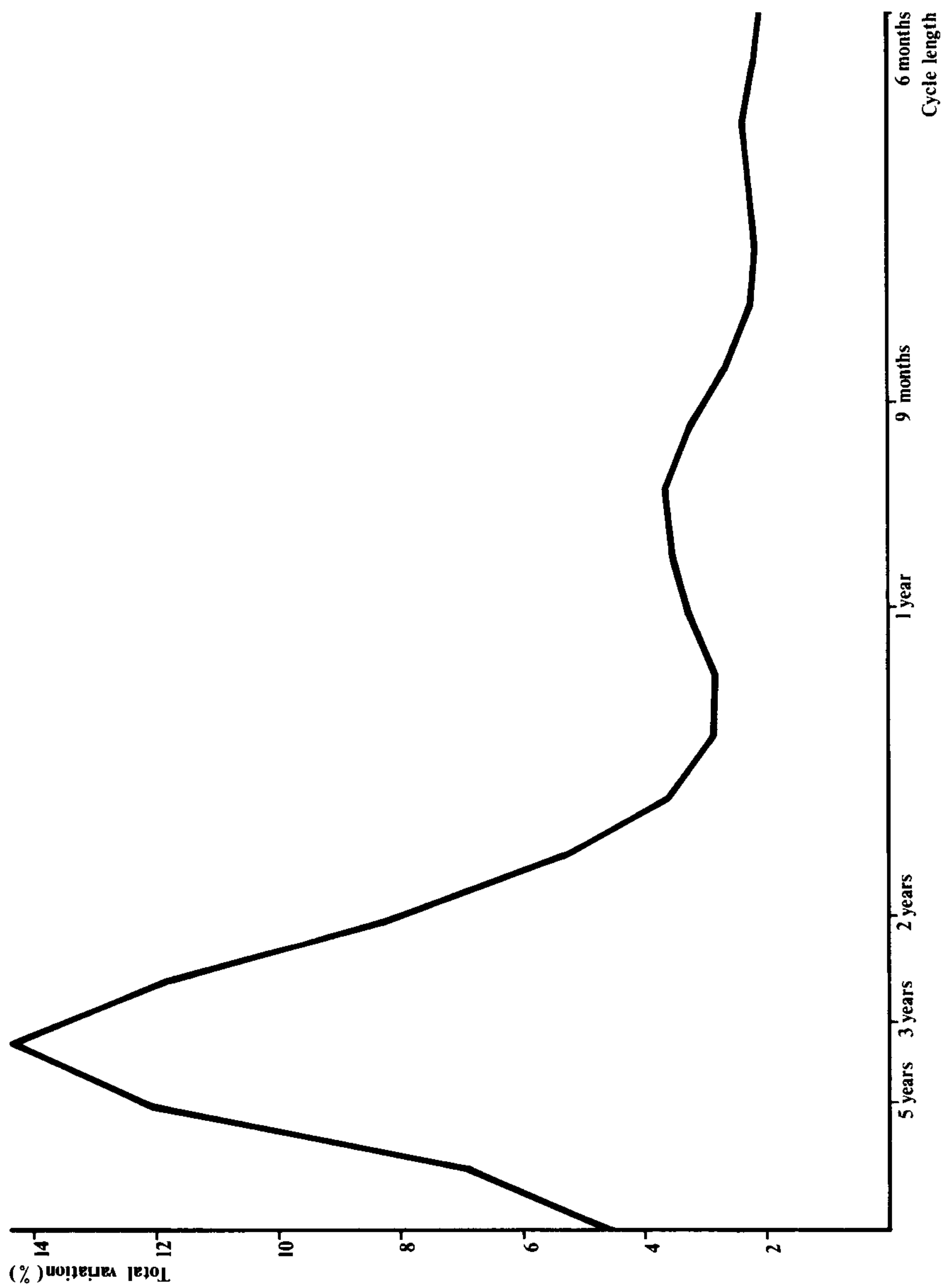

FIGURE 1 — Spectrum of BAE Indicator of Clean Wool Prices: 1958-78

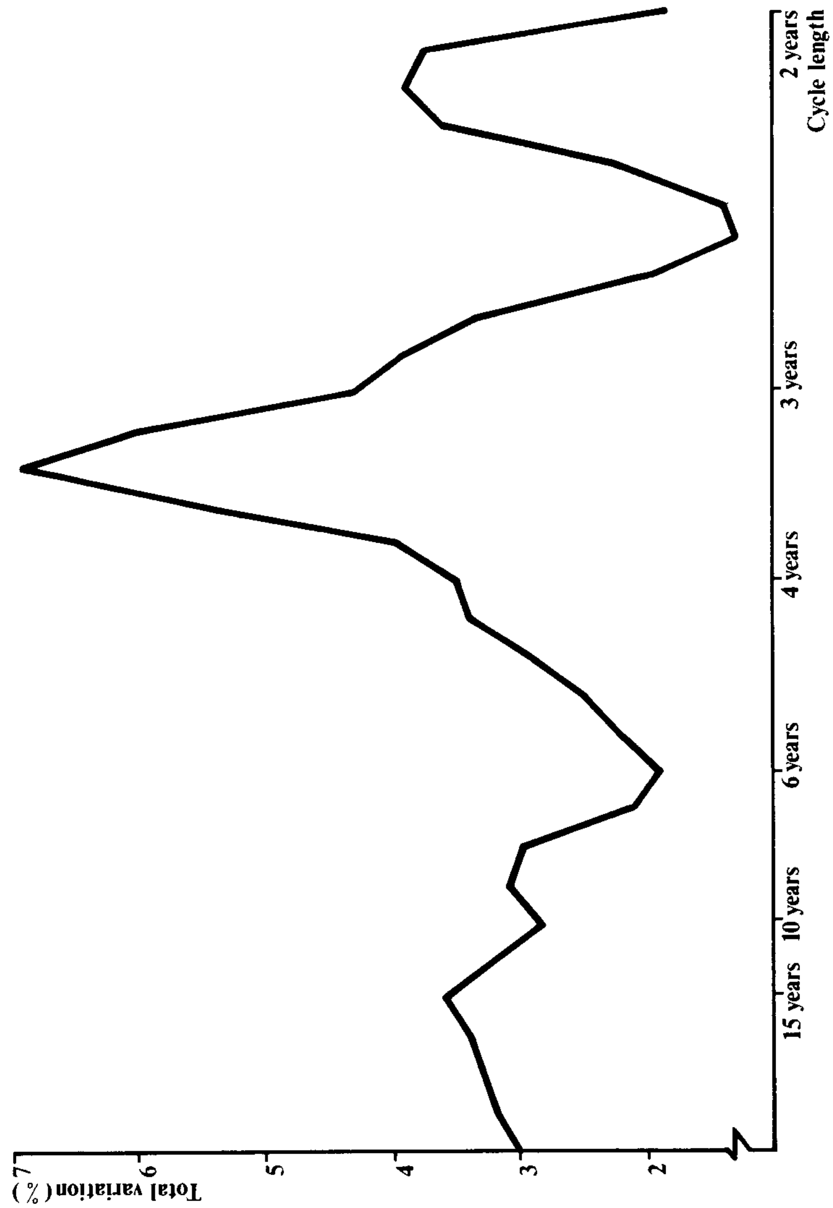

FIGURE 2—Spectrum of Average Greasy Wool Prices: 1861-62 through 1978-79

weights for deviations above and below target values. For example, they may wish to penalise deviations below the price target more heavily than above target deviations. In such a case, a piece-wise quadratic function would be appropriate (see Friedman 1975). However, there is little direct evidence on this point. Consistent with the results obtained by Parton (1979) from a study of actual decision making in the AWC, a quadratic function with price and the stockpile as targets may represent a reasonable initial approximation.

It has also been suggested by referees that the stockpile and price targets may not be independent. However, there is no firm evidence on this point. Unless the relationship between the target variables was linear it would be impossible to accommodate such interdependence in a linear-quadratic optimal-control framework.

Control Variable and Control Period

The natural choice for a control variable was net purchases (sales minus purchases) by the AWC. This is the variable used currently by the AWC to influence market price directly under the MRP and FRP schemes.

A quarterly decision period was chosen. It was felt that a longer period did not give sufficient flexibility to adapt to changing market conditions and provided no information about the required distribution of net purchases over the year. A shorter decision period would be technically feasible but frequent iterations of an econometric model with the appropriate periodicity would be required.

If it were desired to retain an annually-determined MRP it could be integrated with a quarterly optimal net purchase plan. One approach might be to forecast the minimum market price expected over the year, given that the optimal net purchase plan was implemented, and set the MRP at this level. However, this problem is not pursued here.

Control Algorithm

The final issue to consider in setting up the optimal-control problem was the choice of a control algorithm. Given the decisions to use a quadratic welfare function and a linear econometric model, a linear-quadratic algorithm was required. The main problems to be resolved were how to deal with uncertainty about parameter values and the particular algorithm to use. The possibility of improving knowledge about parameter values through active learning was ruled out, since experimental control settings are generally not politically feasible in economics (but see Rausser and Freebairn 1974). Furthermore, if the information available about parameter values at the beginning of the control period is large relative to the information that will become available during the control period, the loss from ignoring this additional information is likely to be relatively small. The scope for a gain from learning is likely to increase with the degree of uncertainty about parameter values (Prescott 1972).

It was decided to use an algorithm taking account of uncertainty about parameter values. In most economic applications there will be uncertainty about parameter values and an algorithm which allows for this should result in superior policies to one that does not. For comparison, results are also presented using an algorithm based on the less computationally burdensome certainty-equivalence principle (i.e. parameter values and the disturbance term are set equal to their expected values so that the control solution is identical to the one obtained if the model were treated as deterministic).

The algorithm used is described in Chow (1973, 1975) and is based on the assumption that parameter values are constant but not known with certainty. The major approximation made in implementing Chow's algorithm is to interpret the reduced form covariance matrix of coefficients as a covariance matrix of the random parameter π around the constant $\bar{\pi}$ rather than as a covariance matrix of the random estimates π. Thus, the control solution is computed under assumptions which differ from those used in estimation. Craine and Havenner (1977) attempted to overcome this problem by replacing Chow's closed-loop algorithm (i.e. the second-period policy is based on the first-period outcome) with a random parameter version of Theil's open-loop algorithm (i.e. optimal policy for each period is fully determined at the beginning of the control period) under the assumption that the first-period solution of these two algorithms is equivalent. However, first-period equivalence has been demonstrated by Norman (1974) only for linear models with known coefficients and an additive disturbance.

Holbrook and Howrey (1978) have shown, with a specific random coefficient example, that the Chow and Theil solutions for the first period in general will differ. Furthermore, the Chow solution results in a smaller expected loss. While it is difficult to generalise these results, Holbrook and Howrey conclude that, if the Chow algorithm is used in a truly closed-loop fashion, then the expected outcome of the Chow policy will be superior over both the short run and the long run. If the optimal-control approach were to be applied to the wool stabilisation problem, it is expected that it would be used in a closed-loop fashion. Hence, the Chow algorithm was preferred.

General Form of Control Problem

To summarise the discussion so far, the general structure of the control problem examined in this paper took the form:

$$\text{(1)} \qquad \min W = E_o \sum_{t=1}^{T} \alpha^{t-1}(y_t - a_t)'K(y_t - a_t),$$

subject to:

$$\text{(2)} \qquad Y_t = Ay_{t-1} + Cx_t + Bz_t + u_t,$$

where E_o = expectation conditional on all information available at period 0;

$\alpha = 1/(l + r/n)$;

r = annual discount factor;

n = number of periods in a year;

y_t = vector of endogenous and control variables;

a_t = vector of target values;

K = symmetric, positive semi-definite matrix of penalty weights;

A, B, C_t = coefficient matrices whose elements are constant but unknown, with known means and covariance matrices;
x_t = vector of control variables;
z_t = vector of values of exogenous variables; and
u_t = is a serially uncorrelated vector with a mean of zero.

Thus, the welfare function was quadratic and the problem was to minimise the sum of squared deviations of target variables from target values over the control period subject to the econometric model. In some applications, discounting was used and this is discussed below. There were only two target variables in the wool price stabilisation problem. Positive weights on the diagonal of K were assigned to correspond to the price and stockpile variables and all other elements were zero.

A stockpile identity $S_t = NP_t + S_{t-1}$ was added to the reduced-form equations. This represented a system of higher-order difference equations, given the 12-quarter moving-average price term in the demand and supply equations. This system was converted into a system of first-order difference equations and the control variable NP_t added to the vector y_t to conform to Chow's general equation system. In order to reduce required computer storage, Chow's algorithm was modified to allow the elimination of lagged control and endogenous variables with zero coefficients in the final reduced-form coefficient matrix. It was also necessary to derive the asymptotic reduced-form variance-covariance matrix of columns of coefficients from the variance-covariance matrix of coefficients. This was done using the procedure described in Goldberger, Nagar and Odeh (1961).

Derivation of Results

In this section the effects of AWC buying and selling under the Reserve Price Scheme are compared with the predicted effects of applying optimal-control policies over the period 1970 to 1979.

Method

If it were desired to rank the alternative policies in terms of preferred outcomes, the following conditions should be met:

(a) the same welfare function is used by the AWC as in the optimal-control analysis;
(b) the same model is used to evaluate the effects of the alternative policies; and
(c) the same information set is used in deriving the alternative policies (i.e. the same forecasts of exogenous variables and error terms were used).

It is unlikely that any of these conditions held exactly and, hence, no strict comparison in terms of preferred outcomes is possible. It would be possible to compare predicted outcomes without making welfare judgments but such an exercise would be of little interest. Thus, it is necessary to attempt to assess to what extent the failure to meet the above three conditions invalidates a welfare comparison.

Welfare function

The possibility of some divergence between the welfare function used and that of the AWC was discussed above but no firm evidence was available. A further difficulty arises from the level of aggregation used in modelling. Over the period considered, some AWC intervention may have been directed at influencing price relativities among different wool types but the effects of this activity cannot be evaluated given the aggregate model used.

Model

If the wrong model is used to derive an 'optimal-control policy', then it is possible that a non optimal-control policy may yield a preferred actual outcome (see Chow 1977 for an example). On the other hand, it is also possible that, if the wrong model is used, the superiority of an optimal-control policy may be understated. In order to relieve dependence on a single model in such comparisons, Chow (1977) has suggested combining the results from several models. This option was not feasible in the present study since, as mentioned above, a model had to be developed especially to satisfy the requirements of this study. Nevertheless, it is worth noting that, on the basis of the results obtained from the model used here, the AWC has had a rather more favourable impact on price stability than it would seem from the results obtained by Campbell, Gardiner and Haszler (1980), although the two sets of results relate to a slightly different time period.

Information set

If the alternative methods of determining policy are to be compared over a given historical period, then it seems reasonable to require that the same information set be available in each case. This implies that, in deriving optimal-control policies at time t, only the known values of exogenous variables at $t-1$ should be used to forecast future values. At time $t+1$, the optimal-control policy could be revised in the light of new information on the values of exogenous and endogenous variables at time t.

Unfortunately, it was impossible to use this method in deriving the optimal-control policies. There were insufficient observations for some of the exogenous variables prior to the simulation period to permit reasonable forecasts of their values over the simulation period. Furthermore, a prohibitive amount of computer time would have been required for the 37-period control problem. For each set of penalty weight ratios, a new optimal solution would need to be computed over the entire control period for each of the 37 periods.

It was decided simply to assume that the authorities were able to forecast correctly the values of exogenous variables over the entire control period at the beginning of the period. This assumption clearly favours optimal-control policies in comparison with alternatives. It would be possible to analyse the sensitivity of the results to different assumptions about possible errors in the forecast of exogenous variables. However, the information set requirement is already technically violated by the fact that the model used to evaluate the effects of the alternative policies uses information that became available only during the simulation period. Furthermore, the assumption about exogenous variables does not necessarily mean that the overall results are biased in favour of optimal control. If the 'wrong' model is being used it may be one that is unfavourable to optimal control.

Disturbance term

A final issue relating to the information set involved the treatment of the disturbance term in the model in the historical simulations. There were three possibilities:

(a) set the disturbance term equal to its expected value of zero;
(b) set the disturbance term equal to its estimated value for the historical period; or
(c) undertake a Monte-Carlo study to generate different possible realisations of the disturbance term.

The first approach is the one usually adopted in deriving optimal-control policies over a forecast period since, by definition, the value of the disturbance term cannot be forecast. The only difficulty in applying this approach to the historical simulation is that, since the model takes the form:

$$(3) \qquad y_t = AY_{t-1} + Cx_t + Bz_t + u_t,$$

which includes the lagged dependent variable, the effect of the Reserve Price Scheme would be simulated as resulting in values of y_t not necessarily equal to the historically observed y_t. The historically-observed values would be obtained using the second approach but this would require the assumption that the authorities correctly forecast the disturbance term. In the third approach, a number of comparisons between the Reserve Price Scheme and the optimal-control approach could be made for different realisations of the disturbance term.

While each of these approaches has its merits, the first was adopted mainly on the grounds of simplicity. Some preliminary work was done using the second approach but the results obtained about the potential gain from adopting optimal-control policies were very similar to those obtained using the first approach. The third approach would provide additional information but was not undertaken due to the heavy computational burden. The results presented using the first approach (i.e. setting the disturbance term equal to its expected value of zero) could be interpreted as the mean result if the period were repeated an infinite number of times with different realisations of the disturbance term.

Simulation results

As a preliminary to the optimal-control analysis, two sets of simulations were run over the period 1970 (IV) to 1979 (IV) using the econometric model to try to establish the historical impact of AWC intervention on price and other variables. In both sets of runs, exogenous (i.e. non-control) variables were set equal to their observed historical values. In the first set of runs, the disturbance term was set equal to its estimated historical value. The effect of AWC intervention was simulated by setting AWC buying and selling equal to their historical values. The effect of no AWC intervention was simulated by setting AWC buying and selling equal to zero. In the second set of runs, the disturbance term was set equal to its expected value of zero and AWC buying and selling was set equal to their historical values and then zero.

A number of measures of variability for selected variables in these simulation runs are presented in Table 2. Since price was trending upwards exponentially over the period, the mean is not an ideal measure of central tendency. Hence, the coefficient of variation may not be the most appropriate measure of variability. The price series were transformed to percentage-change form to make them stationary. The standard deviation of the series in this form is presented as an alternative measure of variability.

A measure of the variability of revenue is provided. Revenue is defined simply as price multiplied by receivals (adjusted to a clean basis) in a given quarter. Since there is a time lag averaging about two months between receivals and sales and some wool received may be withdrawn from sale, this measure only approximates grower revenue in a given quarter.

The results under both sets of assumptions about the disturbance term are quite similar. For the historical results, it appears that AWC intervention had quite a significant impact in reducing the variability of price. The variability of supply and revenue also was reduced. Although mean price was slightly lower, a higher level of supply was obtained and mean revenue per quarter was increased marginally.

Control results

For the optimal control analysis, the welfare function contained price and the stockpile as arguments. The discount factor, α, was set equal to unity since it was assumed that exogenous variables were forecast correctly. In all of the results reported in this section the disturbance term was set equal to its expected value of zero.

The price target set was formed by constructing a 3-year moving average of prices forecast in the absence of AWC intervention. The stockpile target was set at a relatively low constant value of 20 kt greasy.

The control properties of the model enabled a price target to be attained exactly each period (in a deterministic control framework) if no weight was given to attaining the stockpile target. However, exact attainment of the price target involved an infeasible policy because a negative stockpile was required in certain periods. The problem was that stocks that were initially accumulated when prices were falling were not sufficient for required sales during the next period of rapidly rising prices.

A number of control runs were then undertaken, giving increasingly higher relative weights to the stockpile target. The problem of a negative stockpile continued to recur in certain periods even with a relatively high weight on the stockpile target.

It was decided to increase the stockpile target in periods for which the problem of negative stocks had occurred in earlier runs. The stockpile target finally chosen ensured that stocks were just non-negative during these periods when the penalty weights on the price and stockpile targets had the ratio of 5:1.

The results of a number of these runs with increasingly higher relative weights on the stockpile target are reported in Table 3. The deviation of target variables from target values is measured by the Root Mean Square

TABLE 2

Simulations without and with AWC Intervention: 1970 through 1979

Run	Standard deviation of percentage Change		Coefficient of variation				Mean		
	Local price	User price[a]	Local price	User price[a]	Supply	Revenue	Price	Supply	Revenue[b]
	%	%	%	%	%	%	c/kg clean	kt greasy	$m
	Disturbance term equal to estimated historical value								
No AWC intervention	20.3	21.1	45.1	42.9	46.3	63.4	267	166	258.8
AWC intervention	13.9	15.4	33.5	33.6	41.5	50.1	258	172	266.4
	Disturbance term equal to zero								
No AWC intervention	12.7	13.9	37.3	35.0	50.3	61.9	257	161	255.5
AWC intervention	10.0	11.8	29.0	29.9	46.8	53.0	247	175	259.7

[a] Local price adjusted by Treasury exchange rate index.
[b] In calculating revenue in this and other tables, supply was converted from a greasy to a clean basis by adjusting by the mean yield for the period 1970 through 1979.

Percentage Deviation (RMSPD) defined as:

$$\text{(4)} \qquad \text{RMSPD} = \sum_{t=1}^{T}[((O_t - U_t)/U_t)^2]^{0.5}/T \times 100,$$

where O_t = outcome of target variable;
U_t = specified target value; and
T = length of control horizon.

In the case of net purchases, percentage deviations are measured from a target value of one to give an indication of the intensity of instrument use.

Some further results for these optimal-control runs are given in Table 4. The average capital required refers to the mean value of purchases and sales per quarter. No account is taken of storage costs or the costs of moving wool into and out of store. These costs are also ignored in calculating the operating profit from purchases and sales over the period. In the absence of detailed information about these costs, they might be assumed to be a linear function of the average size of the stockpile over the control period. Thus, the average size of the stockpile could be interpreted as a proxy for storage costs in the subsequent analysis.

In all of the control runs, mean price and revenue were not significantly different from that predicted in the absence of AWC intervention. The mean level of net purchases by the end of 1979 (IV) lay in the range 0 kt to 1 kt. Thus, most stocks accumulated over the control period had been disposed of by the end of the period.

It is interesting to compare the results for optimal control with those for the actual pattern of AWC intervention. However, the three conditions outlined above needed to rank these results should be borne in

TABLE 3

Optimal-Control Runs: 1970 through 1979

Run[a]	Penalty weight ratio	First-period net purchases	RMSPD[b]			Mean		Maximum stocks
	Price:stocks		Price	Stocks	Net purchases	Price	Stocks	
		kt	%	%	%	c/kg	kt	kt
No AWC intervention			3.00			257		
AWC intervention		14.1	2.74	—	485.5	247	105.3	262
CE	5:1.0	32.9	1.79	35.0	318.8	256	38.3	138
PU	5:1.0	12.9	1.84	37.3	327.0	255	35.0	155
CE	5:1.1	33.8	1.94	34.5	315.7	255	38.2	134
PU	5:1.1	13.8	1.92	35.9	314.8	257	35.6	151
CE	5:1.25	35.1	2.07	32.6	302.8	255	38.1	128
PU	5:1.25	15.1	2.04	34.1	300.1	255	35.6	145
CE	5:1.5	36.8	2.25	30.0	290.4	255	38.0	120
PU	5:1.5	16.8	2.21	31.5	283.1	255	35.7	136
CE	5:1.75	38.0	2.40	27.9	286.0	256	38.0	113
PU	5:1.75	18.2	2.35	29.4	273.3	255	35.9	129
CE	5:2.0	38.9	2.54	26.0	286.7	256	38.0	120
PU	5:2.0	19.5	2.48	27.6	268.5	255	36.0	122

[a] CE = certainty equivalence; PU = parameter uncertainty.
[b] RMSPD = root mean square percentage deviation.

mind. The two sets of results can be compared for the stockpile levels needed to attain a given level of price stability and show that, with optimal-control policies, a significantly smaller average stockpile was needed to attain a given level of price stability. In all of the control runs, as might be expected, closer adherence to price target values, as measured by the RMSPDs, was achieved than with the actual pattern of AWC intervention. The absolute level of price variability was also lower on most runs. This improved stability applied to users when prices were adjusted by the exchange rate index. However, the most important result is that this greater price stability was achieved with a mean stockpile less than one-half the size of that actually maintained by the AWC, significantly lower average capital requirements and, in many cases, considerably higher operating profits. The results for price and stockpile size for AWC intervention, no AWC intervention and optimal-control when the penalty weights on the price and stockpile targets had the ratio of 5:1 are shown in Figure 3.

It appears from the results that a slightly higher level of revenue stability was achieved by AWC intervention than by the optimal-control runs. However, revenue stability has not been taken as a policy aim. If it were desired to make it an aim, a nonlinear control algorithm would really be needed since revenue involves a multiplicative relationship between price and quantity.

Finally, it is of interest to compare the parameter-uncertainty results with the certainty-equivalence results. Although there is some belief that taking account of uncertainty will result in 'less aggressive' policies, it can be shown that, in general, no *a priori* predictions can be made and the

TABLE 4

Additional Results from Optimal-Control Runs: 1970 through 1979

Run[a]	Penalty weight ratio	Standard deviation of percentage change in price	Coefficient of variation		Mean revenue	Average capital	Operating profit
	Price:stocks		Supply	Revenue			
		%	%	%	$m	$m	$m
No AWC intervention		12.7	50.3	61.9	254.5		
AWC intervention		10.0	46.8	53.1	259.7	34.1	9.7
CE	5:1.0	8.5	49.2	59.4	262.9	21.6	14.9
PU	5:1.0	9.3	48.9	58.3	260.2	22.8	42.3
CE	5:1.1	8.7	49.2	59.5	262.9	20.9	12.9
PU	5:1.1	9.5	49.0	58.5	260.1	23.6	37.9
CE	5:1.25	9.2	49.2	59.6	262.7	20.2	9.7
PU	5:1.25	10.0	49.0	58.7	260.1	20.4	31.7
CE	5:1.5	9.8	49.3	59.8	262.4	20.0	3.9
PU	5:1.5	10.4	49.1	58.9	260.1	19.3	22.6
CE	5:1.75	10.3	49.4	60.0	262.1	19.5	−1.9
PU	5:1.75	10.9	49.2	59.1	260.0	18.8	14.6
CE	5:2.0	9.8	49.3	59.8	262.0	19.3	−8.8
PU	5:2.0	11.3	49.2	59.4	260.0	18.8	7.4

[a] CE = certainty equivalence; PU = parameter uncertainty.

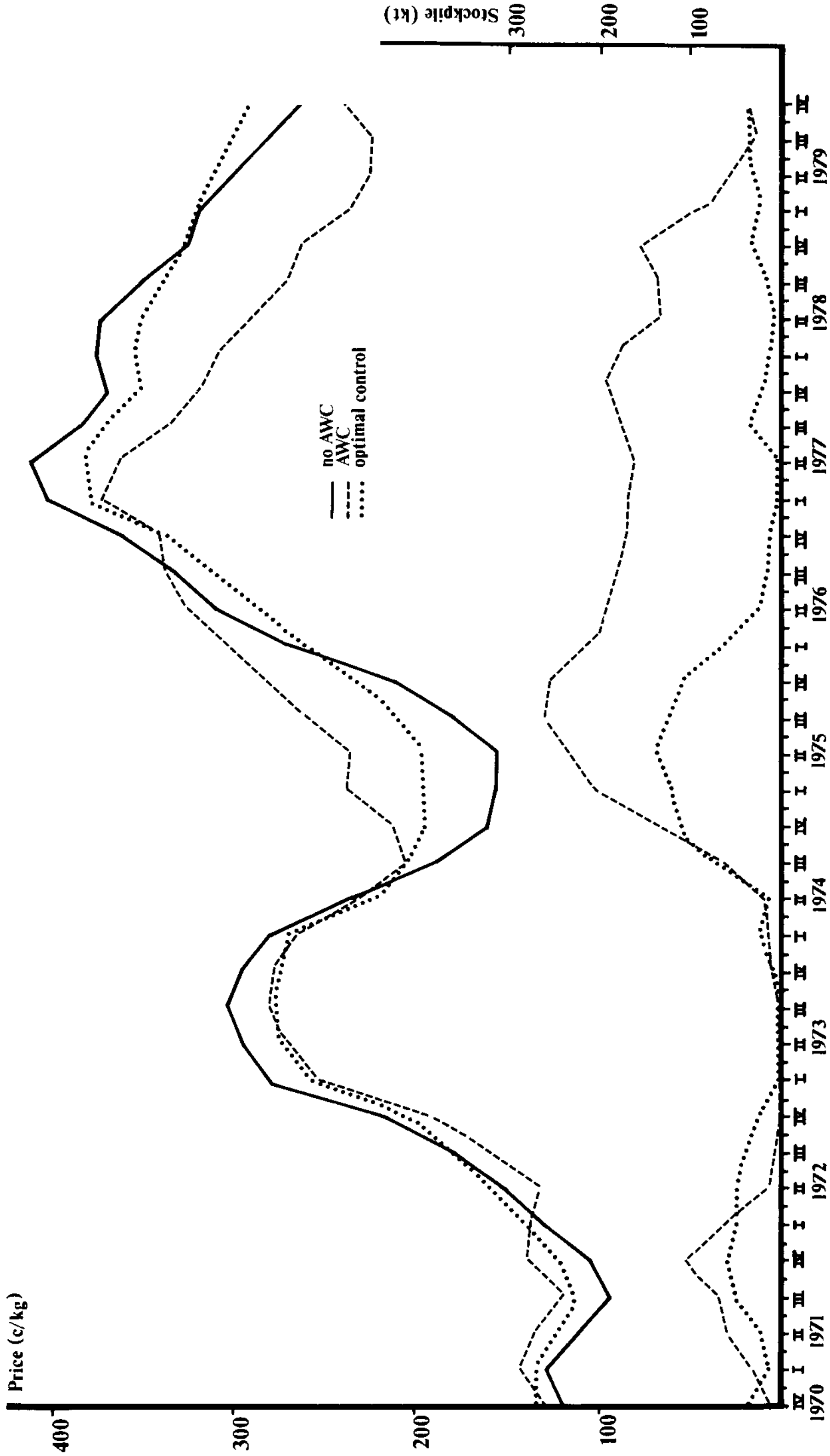

FIGURE 3 — Results for AWC, no AWC and Optimal Control

outcome depends entirely on model structure (Chow 1975). For the present model, the parameter-uncertainty algorithm resulted in a smaller first period policy (i.e. absolute value of net purchases) and generally 'less aggressive' instrument use (as measured by the RMSPD for net purchases) over the control period. The policies, when the penalty weights on the price and stockpile targets had the ratio of 5:1.75, are compared in Figure 4.

The second set of control results relate to the forecast period 1980 through 1987. The aim of this exercise was to bring the analysis closer to an actual operating environment. The exogenous variables in the model were forecast using a variety of methods described in Table 5. A 32-period forecast horizon was chosen, as this was the time required for the coefficients in the optimal control feed-back equations to converge to an approximately constant value (Chow 1975, p. 172). The price target set was based on a 3-year moving average of prices forecast in the absence of AWC intervention. The stockpile target was set at a constant value of 20 kt a quarter.

Control runs with values of the discount factor α, ranging from 1 to 0.85 were undertaken. There were two reasons for using a discount factor over the forecast period. The first is the standard argument that consumption of a good or service (in this case, price stability) is preferred now rather than later. The second reason stems from the widening confidence intervals for forecasts of exogenous variables as the time horizon lengthens. As a result, it may be wise to discount the influence of more distant forecasts on more immediate policies and secure closer adherence to more immediate target values at the expense of greater deviations from more distant ones.

The results of a sample of control runs are summarised in Tables 6 and 7, the interpretation of which is similar to that of Tables 3 and 4. Prices, in the absence of AWC intervention, were forecast to exhibit relatively less varibility than over the historical period 1970 through 1979. Consequently, for given penalty weight ratios, it was possible to make prices adhere more closely to target values with relatively less intensive instrument use and a smaller mean stockpile.

In all of the optimal-control runs, mean price and revenue were not significantly different from that forecast in the absence of AWC intervention. In all of the runs reported, mean net purchases lay in the range -1 kt to 0 kt (a positive stockpile existed at the beginning of the period). Thus, most of the stocks accumulated over the control period had been disposed of by the end of the period.

Exact attainment of the price target was possible under a (deterministic) formulation of the problem without stocks becoming negative.

TABLE 5

Forecasts of Exogenous Variable

Variable	Forecast method
Diffusion index	ARIMA model
Exchange rate index	Mean value 1979
Wheat prices	BAE trend forecast
Shearing costs	BAE trend forecast

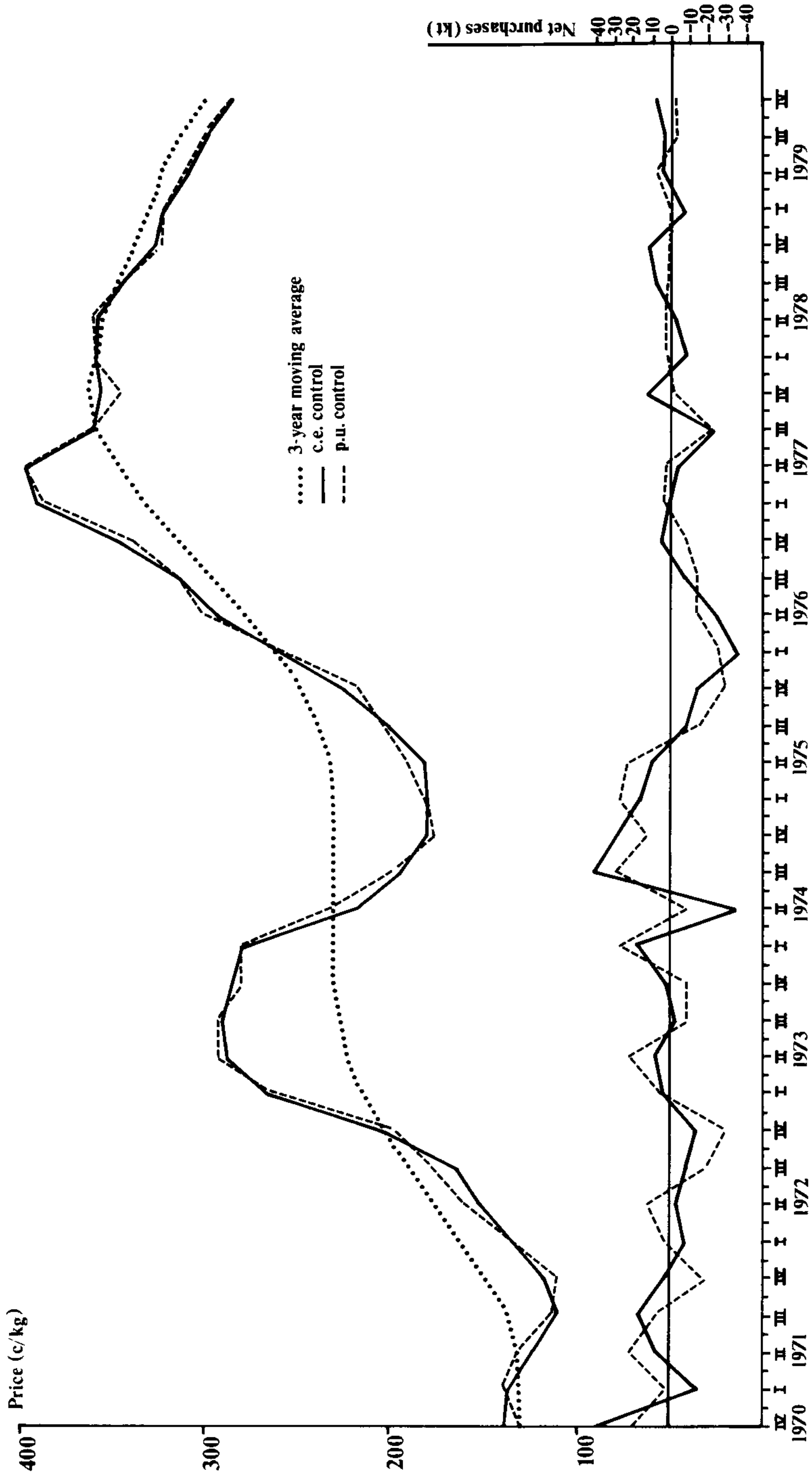

FIGURE 4—Comparison of C.E. and P.U. Runs

TABLE 6

Optimal-Control Runs: 1980 through 1987

Run[a]	Penalty weight ratio	First-period net purchases	RMSPD[b]			Mean		Maximum stocks
	Price:stocks		Price	Stocks	Net purchases	Price	Stocks	
		kt	%	%	%	c/kg	kt	kt
		Discount factor = 1.0						
No AWC intervention	0:0.0	–	0.68	–	–	433	–	–
CE	5:0.0	8.0	0.00	63.4	337.9	427	80	146
CE	5:0.05	– 10.5	0.11	26.2	314.6	427	33	86
CE	5:0.1	– 13.5	0.13	22.4	303.4	428	28	77
CE	5:0.5	– 18.0	0.21	14.8	242.4	429	16	56
PU	5:0.5	– 19.7	0.32	19.7	200.2	429	16	42
CE	5:1.0	– 17.8	0.25	12.0	196.5	430	19	48
PU	5:1.0	– 20.5	0.36	14.5	185.3	429	16	43
CE	5:1.5	– 17.3	0.28	10.4	166.8	430	19	43
PU	5:1.5	– 20.4	0.38	12.3	174.5	430	19	37
CE	5:2.0	– 17.0	0.30	9.3	146.1	430	19	31
PU	5:2.0	– 20.2	0.39	11.0	165.1	430	15	35
		Discount factor = 0.9						
CE	5:0.5	– 4.0	0.09	32.9	317.7	428	40	92
CE	5:0.1	– 6.0	0.12	28.1	306.0	428	34	87
CE	5:0.5	– 10.7	0.23	16.8	238.9	429	23	61
PU	5:0.5	– 17.5	0.33	22.5	176.8	429	10	34
CE	5:1.0	– 12.3	0.30	12.1	190.9	430	20	44
PU	5:1.0	– 17.6	0.37	14.7	152.5	430	12	32
CE	5:1.5	– 13.1	0.35	9.6	160.6	430	20	44
PU	5:1.5	– 17.6	0.40	11.4	136.8	430	13	31
CE	5:2.0	– 13.6	0.39	8.3	143.2	428	20	40
PU	5:2.0	– 17.5	0.43	9.4	129.2	428	14	30

[a] CE = certainty equivalence; PU = parameter uncertainty.
[b] RMSPD = root mean square percentage deviation.

TABLE 7

Additional Results: Optimal-Control Runs: 1980 through 1987

Run	Penalty weight ratio	Coefficients of variation			Mean revenue	Average capital	Operating profit
	Price: stocks	Price	Supply	Revenue			
		%	%	%	$m	$m	$m
			Discount factor = 1				
No AWC	0:0	16.3	51.5	49.0	401.6	—	—
CE	5:0	12.9	49.7	47.8	409.4	36.2	19.3
CE	5:0.05	13.2	50.0	48.2	403.8	34.8	185.5
CE	5:0.1	13.3	49.9	48.1	404.0	34.2	169.6
CE	5:0.5	13.7	49.7	49.8	404.7	28.4	106.3
PU	5:0.5	13.7	50.1	47.3	400.0	24.6	205.4
CE	5:1.0	13.9	49.7	47.8	404.6	23.3	404.6
PU	5:1.0	14.0	49.9	47.3	401.1	22.1	136.7
CE	5:1.5	14.1	49.8	47.8	404.4	19.8	75.6
PU	5:1.5	14.2	49.9	47.2	401.5	20.9	107.6
CE	5:2.0	14.3	49.9	47.8	404.1	17.3	69.9
PU	5:2.0	14.3	50.0	47.3	401.6	19.3	91.6
			Discount factor = 0.9				
CE	5:0.05	13.2	50.4	48.4	403.1	34.1	205.7
CE	5:0.1	13.4	50.4	48.5	402.3	33.2	217.6
CE	5:0.5	14.1	50.4	48.5	402.5	27.2	143.2
PU	5:0.5	14.2	50.4	47.8	399.3	21.7	209.8
CE	5:1.0	14.5	50.4	48.5	402.7	18.7	103.8
PU	5:1.0	14.5	50.3	47.8	400.5	18.9	138.1
CE	5:1.5	14.7	50.5	48.4	402.6	18.6	85.8
PU	5:1.5	14.7	50.4	47.9	400.9	16.8	108.4
CE	5:2.0	14.9	50.5	48.4	402.5	17.7	75.6
PU	5:2.0	14.9	50.4	47.9	401.1	17.0	92.1

However, under the parameter-uncertainty formulation, the problem of negative stocks emerged for low relative weights on the stockpile target. These results are not reported since they represent infeasible policies.

In comparing the certainty-equivalence results with the parameter-uncertainty results, the following points were evident:

(a) in general, the first-period policy of the parameter-uncertainty runs was larger in absolute value than the certainty-equivalence runs;
(b) the parameter-uncertainty runs resulted in 'less aggressive' instrument use over the entire control horizon except when there was no discounting and a relatively high weight was placed on the stockpile target; and
(c) first-period policy was relatively less sensitive to the choice of discount factor with the parameter-uncertainty runs than the certainty-equivalence runs and it appears that, if the optimal-control approach were used in a closed-loop fashion, policy would be relatively insensitive to the choice of discount factor, at least over the range of discount factors and penalty weight ratios considered.

Summary and Conclusions

In this paper it was pointed out that there has been a slow rate of adoption of optimal-control techniques to run stabilisation schemes despite the theoretical advantages of the techniques. It was suggested that three major obstacles have tended to delay their adoption, namely:

(a) the need to use an explicit model (or group of models) in deriving optimal policies;
(b) the need for policy makers to specify an explicit objective function; and
(c) the need to devise a suitable institutional structure in which optimal-control policies can be derived and implemented.

To motivate research to overcome these problems, there needs to be a belief that the gain from the adoption of optimal-control policies could be substantial. Unfortunately, the same obstacles which have delayed the adoption of optimal-control policies make it difficult to show, by historical simulation, that the adoption of such policies would produce unequivocally preferred results. In the present application, it was found that the MRP scheme for wool has had a significant effect in reducing the variability of prices. Nevertheless, it was also shown that optimal-control policies had the potential to achieve a significantly greater degree of price stability at lower stock-holding costs.

It is immediately conceded that these results can be disputed on a number of grounds, such as the form of the model and/or objective function used. The credence attached to the results may largely reflect prior beliefs about the potential advantages of adopting optimal-control methods. It is the authors' prior belief that for a problem with significant dynamic elements, whereby current policy actions influence future policy options, the gain from the adoption of optimal-control policies is likely to be substantial.

If the issue ultimately reduces to one of prior beliefs, the justification for an empirical study, such as the present one, lies in its ability to highlight points of dispute for future research and to clarify the logical structure of the decision problem. Thus, issues such as the effects of changes in the variability of wool prices on user demand and possible changes in the process of fibre substitution are crucial issues for future modelling of the wool market. Similarly, issues such as the optimal weighting of prices in local currency as opposed to user-currency terms and a possible relationship between the price and stockpile targets are important in specifying the objective function.

It may be that no matter how many different models of the wool market are developed, there will always remain room for dispute as to the correct model. In this case, experiments with a weighted group of different models may represent a useful line of development. This could be seen as paralleling the situation where different policy makers have different implicit models. Similarly, the correct specification of the objective function is unlikely to be a problem that is easily resolved. In this case, research into deriving the objective function indirectly by studying policy-makers' rankings of possible alternative outcomes may be most useful.

APPENDIX

Description of the Data

Supply data. These are for quarterly receivals of taxable wool from ABS (1981).

Wool price. The series used is the BAE Clean Price Indicator, being an average of auction prices for wool of different micron counts weighted by throughput of different micron counts in the market to control for seasonal quality patterns (BAE 1981).

Buyers' wool-price expectations. These are approximated by lagging the price series once.

Exchange rate. The data are an official index of average of exchange rates for most of Australia's trading partners weighted by trade value specified as an index of foreign currency units per $A (Source: *The Australian Financial Review*, various issues).

Economic activity. A diffusion index is calculated from a variety of measures of economic activity for each of six OECD countries which are summed (Source: Bureau of Agricultural Economics).

Growers' price expectations. Price expectations for wheat and wool are approximated by distributed lags of BAE estimates of farmers' net returns from wheat per tonne and clean wool prices, respectively. The weights for wheat returns are 0, 0, 0, 0.500, 0.475, 0.400, 0.333, 0.305, 0.280, 0.225, 0.170 and for wool are 0, 0, 0, 0.083, 0.083, 0.083, 0.083, 0.083, 0.083, 0.083, 0.083, 0.083, 0.083, 0.083 and 0.083. The weights for wheat are based on a semi-gamma distribution. There is no *a priori* justification for this lag shape except that values decline back through time and fit the data. The weights for wool sum to one. These two distributions are included in the model as moving-average terms.

Shearing costs. The award rate in dollars per 100 sheep is used as a measure of wool growers' costs (Source: Department of Primary Industry).

References

ABS (1981), *Brokers and Dealers Receivals of Taxable Wool*, Canberra (and previous issues).

AWC (1973), *The Marketing of Australian Wool*, Melbourne.

——— (1978), *A Review of the Australian Wool Corporation Marketing Proposals of December 1973*, Melbourne.

BAE (1981), *Situation and Outlook, Wool*, Canberra (and previous issues).

Campbell, R., Gardiner, B. and Haszler, H. (1980), 'On the hidden revenue effects of wool price stabilisation in Australia: initial results', *Australian Journal of Agricultural Economics* 24(1), 1-16.

Carland, D. J. (1981), An econometric model of wool stockholding under the Reserve Price Scheme. Paper presented to the Annual Conference of the Australian Agricultural Economics Society, Christchurch.

Chambers, R. G. and Just, R. E. (1979), 'A critique of exchange rate treatment in agricultural trade models', *American Journal of Agricultural Economics* 61(3), 249-57.

Chow, G. C. (1973), 'Effect of uncertainty on optimal control policies', *International Economic Review* 14(3), 632-45.

——— (1975), *Analysis and Control of Dynamic Economic Systems* Wiley, New York.

——— (1977), 'Usefulness of imperfect models for the formulation of stabilisation policies, *Annals of Economic and Social Measurement* 6(2), 175-87.

Craine, R. and Havenner, A., (1977), 'A stochastic optimal control technique for models with estimated coefficients', *Econometrica* 45(4), 1013-21.

Dalton, M. E. (1976), 'Dynamic stockholding policies for stabilising the wool market', *Quarterly Review of Agricultural Economics* 29(3), 179-92.

——— and Taylor, E. L. (1975), 'Further developments in a model projecting short-term wool price movements', *Quarterly Review of Agricultural Economics* 28(4), 209-22.

Fama, G. F. (1970), 'Efficient capital markets: a review of theory and empirical work', *Journal of Finance* 25(2), 383-417.

Fisher, B. S. and Tanner, C. (1978), 'In search of Hunt's short run price cycles in the Sydney Wool Futures Market', *Australian Journal of Agricultural Economics* 22 (2 and 3), 129-35.

Freebairn, J. W. (1975), 'Some estimates of supply and inventory response functions for the cattle and sheep sector of New South Wales', *Review of Marketing and Agricultural Economics* 14(1), 53-91.

Friedman, B. M. (1975), *Economic Stabilistaion Policy: Methods in Optimisation*, North Holland, Amsterdam.

Goldberger, A. C., Nagar, A. L. and Odeh, H. S. (1961), 'The covariance matrices of reduced-form coefficients and of forecasts for a structural econometric model', *Econometrica* 29(4), 556-73.

Holbrook, R. S. and Howrey, E. P. (1978), 'A comparison of the Chow and Theil optimisation procedures in the presence of parameter uncertainty', *International Economic Review* 19(3), 749-59.

Hussey, D. D. (1972), *A Short Term Projection Model for Wool Prices—An Exploratory Analysis*, BAE Occasional Paper No. 7, Canberra.

McKenzie, C. J., Philpott, B. P. and Woods, M. J. (1969), 'Price formation in the raw wool market', *Economic Record* 45(111), 386-94.

Norman, A. L. (1974), 'On the relationship between linear feedback control and first period certainty equivalence', *International Economic Review* 15(1), 209-15.

Parton, K. A. (1979), An application of multiattribute utility theory to Australian Wool Corporation decision making. Paper presented to the Annual Conference of the Australian Agricultural Economics Society, Canberra.

Powell, A., Polaseck, M. and Burber, A. T. (1963), 'Synthetic fibres in the wool textile industry: a study of the role of price in technological adjustment', *Australian Journal of Agricultural Economics* 7(2), 210-27.

Prescott, E. J. (1972), 'The multi-period control problem under uncertainty', *Econometrica* 40(6), 1043-58.

Quiggin, J. (1983), 'Wool price stabilisation and price risk for wool users', *Australian Journal of Agricultural Economics* 27(1), 31-43.

Rausser, G. C. and Freebairn, J. W. (1974), 'Approximate adaptive control solutions to U.S. beef trade policy', *Annals of Economic and Social Measurement* 3, 177-203.

Ward, L. E. (1978), An evaluation of the Reserve Price Scheme for wool. Paper presented to the Victorian Branch of the Australian Agricultural Economics Society, Melbourne.

Watson, A. S. (1980), 'Wool in 1980', *Australian Journal of Agricultural Economics* 24(2), 79-93.