Optimal Hedging Strategies for Price Risk Management by Wool Growers: Numerical Sensitivity to Model Formulation, Risk Aversion and Price Expectations

Amanda M. Coad and David J. Pannell*
Agricultural and Resource Economics, The University of Western Australia, Nedlands 6907

Abstract

Since the abandonment of the Reserve Price Scheme in June 1991, Australian wool growers have been left with less protection from fluctuating market prices. This has generated renewed interest in alternative forms of wool price risk management, including hedging with futures.

This paper reports results from a range of hedging models applied to the Australian wool industry. The models include representation of a range of realistic complexities encountered in hedging decisions, including price risk, production risk, basis risk, transaction costs, variation in risk attitudes, and variation in producers' price expectations. The relative importance of each of these complexities in determining the optimal hedging strategy is investigated. The results indicate the high importance of price expectations and the relative unimportance of risk aversion as determinants of hedging decisions.

Introduction

Australian wool growers face two main types of risk, price risk and production risk. Price risk is caused by price volatility. Production risk (quality and quantity risk) comes from climatic and seasonal factors including such things as rainfall and disease (Lubulwa *et al.* 1996). Financial risk is another consideration and comes from sudden changes in such things as interest rates and credit availability (Cunningham 1993).

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The need for price risk management in the wool industry comes about because, like most other agricultural commodities, wool prices are volatile (Bardsley and Harris 1996; Threlfall 1980). This is a result of the demand for wool being highly elastic (Corra 1985; Cunningham 1993) and the supply of wool being very inelastic (Cunningham 1993). The time taken for growers to react to price changes is lengthy because of the nature of Australian wool production in the short term. In the longer term wool supply is more elastic (Cunningham 1993). Price risk management can reduce the effects of price volatility.

The Australian wool futures market was initiated in 1960 in response to high wool price volatility in the 1950's (Lubulwa *et al.* 1996). The reserve price scheme for wool became operational in 1970 in order to stabilise prices for wool growers. The reserve price scheme operated for 21 years until its demise in 1991 leaving wool growers the responsibility of marketing their own wool once again. Growers have certainly become aware of volatile wool prices is since the scheme's demise, and this has led to renewed interest amongst wool producers in the use of forward contracts.

The aim of the paper is to evaluate the relative importance of a wide range of factors in the determination of the economically optimal hedging strategy. A range of models of different degrees of complexity and realism are presented and solved numerically for different levels of risk aversion and different price expectations.

Price risk management alternatives

Since the suspension of the RPS, there has been a much greater interest by growers in various forms of price risk management. These include (a) auction (or the 'spot' market), (b) storage, (c) forward contracts, (d) futures and (e) options on futures.

(a) Auction

Approximately 80 per cent of growers sell their wool to brokers for auction sale on the spot market. It is common for growers to sell their whole clip on a single day at auction regardless of the market situation. Growers can sell through the auction after shearing without any hedging against price risk. A number of studies have investigated the auction selling system (e.g. Angel *et al.* 1990; Beare and Meshios 1990; Cunningham 1993; Stoeckel *et al.* 1990; Ward 1993; Watson and Parish 1982). As Cunningham (1993) writes, wool growers that sell at auction "without any form of price manipulation" will experience "the effects of price volatility and hence, price risk". Consequently, there are marketing alternatives available for growers to use to help combat this risk, forward contracts and futures among them.

(b) Storage

Growers can also store their wool on-farm in their own sheds and sell sometime after shearing. Storage of commodities on-farm can be used as a hedge against price risk when prices are expected to rise in the future (Hertzler and Coad 1996).

(c) Forward Contracts

In the past, efforts have been made to remove some of the uncertainty faced by growers in the auction system by the use of forward contracts for a fixed price and quality of wool. A forward contract is usually priced on the market indicator for wool. A number of private buyers offer growers the option to sell their wool forward and thereby locking in a price for their physical (Cunningham 1993; Hertzler and Coad 1996). There is evidence that farmers prefer forward contracts over futures contracts (Farmline 1996; Nelson 1985; Paul *et al.* 1976).

(d) Futures

Another alternative growers can adopt is futures contracts on the Sydney wool futures market. A grower can take out a contract at the beginning of the year for an end of year sale price. Futures require expertise, effort and time to monitor the markets, and capital for meeting transaction costs and margin calls (Cunningham 1993; Hertzler and Coad 1996; Sydney Futures Exchange 1996). One of the main functions of the futures is to facilitate hedging. Hedging protects against the physical market price volatility (Lubulwa *et al.* 1996).

As Cunningham (1993) noted, Gruen (1960) found that the basic reason for wool growers to trade futures "is to limit their price exposure between the time of shearing and the sale of the clip. This means that wool growers can lock in a price at the time of shearing if the price is desirable. In this case it does not matter whether the prices rise or fall during the time of the hedge the grower will be assured of receiving a price close to the futures price at shearing time" (Lubulwa *et al.* 1996).

There are possibly many benefits of using wool futures. As Cunningham (1993) outlined, Arnott (1992) identifies the four main benefits of using wool futures as

1. the reduction of risk through various hedging strategies,
2. the option to opportunity price because of price volatility,
3. the ability to have trading stances in both the cash and futures markets so as to realise a profit from movements in price in either market, and
4. price discovery (the generation of future expected prices of a commodity) which is useful in making production decisions.

Adjusting wool production is not always an easy risk reducing response for growers. Production plans that are already in action have to be continued until sale time. Therefore, other types of risk responses are required. One such response is trading a risky prospect for a safe one. Generally, there is a cost involved in exchanging risk which is a lower return on the safe prospect than is expected on the risky prospect (Robison and Barry 1987). Futures markets allow growers to do just this. By guaranteeing the grower a future price, risk can be shifted by hedging without having to adjust the quantity of wool produced. Australian wool growers have the opportunity of using futures markets to help stabilise the prices received for their production (Threlfall 1980). Because price volatility is a major cause of income instability, stabilising prices should also help stabilise income (Threlfall 1980).

(e) Options on Futures

A strategy, recently made available to wool growers, is options on futures. Growers can purchase call options which give them the right but not the obligation to purchase futures contracts at the exercise price guaranteed by the contract.

In this paper, we only consider spot selling, forward contracts and futures. Forward contracts and futures, however, are not utilised to a very wide extent in the wool industry. As Threlfall (1980) mentioned, Phillips (1966) found that 99 percent of Australian wool growers did not use the wool futures market (Threlfall 1980). Reasons for this included such factors as:

1. not knowing the potential benefits of futures,
2. the lack of information on how to use futures,
3. when prices are high, futures are at a discount perceived as to large,
4. not wanting to risk the wool price rising after selling futures,
5. and such views as, futures markets harm the wool industry.

The situation has not much changed since Phillips' observations. Preatz (1965) surveyed 560 wool growers and found that only 5 had used futures before (Malcolm 1994). A 1996 Kondinin Group Profarmer survey indicated that of the 131 farms, 95 percent sell to auction and 72 percent plan to, 18 percent sell forward to a marketing board or to a private buyer and 32 percent plan to, 7 percent are hedging with futures and 26 percent plan to use them, 1 percent are hedging with put or call options and 30 percent plan to use them (Farmline 1996). Though it is a useful indicator, this survey is a very biased indicator for this papers' purposes[1].

For Canada and the United States of America, evidence suggests that between five and twenty per cent of primary producers use futures markets to manage their price risks (Berck 1981; Eidman 1994). Forward contracts, futures contracts and options on futures contracts are used widely by Australian cotton growers through the New York futures exchange and to a certain extent by Australian wheat growers through the Chicago futures exchange. Australian wheat and wool growers can use futures provided by the Sydney Futures Exchange, although the liquidity of the markets are often questioned (Dick 1996). There is then a need for wool growers to be able to easily access information on the advantages and disadvantages of alternative forms of price risk management and to then access the actual instruments.

[1] The Profarmer statistics are from a select group of growers that wished to trial Profarmer for free and some were picked out for a free trial based on a fact that they were big producers. All were Kondinin Group members.

Wool Growers' Attitudes Toward Risk

Most wool growers prefer more stable incomes and therefore prices and so will seek price risk management alternatives in order to achieve this (Cunningham 1993). Wool growers vary in their attitudes toward risk. The literature indicates that most farmers are risk averse (e.g., Bond and Wonder 1980; Fransisco and Anderson 1972) and would therefore be willing to accept lower income on average in exchange for less risky or less volatile income (Bardsley and Harris 1987; Binswanger 1980; Feder *et al.* 1980; Fraser 1986; Newbery and Stiglitz 1981; Rogers 1983). Price risk management alternatives can be useful for a risk averse wool grower in securing reasonable prices for the end of the year.

Risk averse growers are willing to give up a part of their income in order to gain the remainder at a certainty. Growers are mostly risk averse in their decision making, and so their utility is increased if price or quantity risk can be reduced (Petzel 1984). Hence, risk averse growers in the wool industry need methods of reducing the risk that occurs in the 'free' market. If growers can adopt a method which manages price risk, they would be better off from the utility of a more certain income. Hence, a risk averse wool grower wants to adopt risk management tools to reduce price uncertainty. This occurred in the late 1950s and 1960s and lead on to the commencement of the Reserve Price Scheme which eventually failed leaving growers seeking alternative means to manage price risk and reduce income uncertainty (Cunningham 1993).

Risk averse behaviour is accepted throughout the literature as being the norm, but the question of whether risk aversion is constant, decreasing, or increasing with increasing wealth still remains unclear. Decreasing absolute risk aversion (DARA) is supported by some empirical evidence, but the choice between relative (RRA) and partial relative risk aversion (PRRA) is less clear (Hamal and Anderson 1982; Pope and Just 1991). We have assumed for convenience that an increase in wealth (W) leads to no change in absolute risk aversion (constant absolute risk aversion, or CARA), where,

$$ARA = -U''/U'.$$

Bond and Wonder (1980) observed that while their results established the relevance of risk attitudes in theory, there remains the empirical question of whether risk parameters are of sufficient size to make any real difference to hedging ratios that might be observed in practice. Empirical estimates of individuals' risk attitudes are sparse, and there are difficulties in comparing across the various studies.

This paper is designed to compare various levels of risk within the wool growing system. Models of various complexities are compared in order to assess what the most important features of price risk management are.

Features of the Models

The literature in this area is vast. Many types of models with different complexities for many different commodities have been investigated over the years. The complexities investigated in this paper for wool include price risk, production risk, basis risk, transaction costs, variation in risk attitudes, and variation in producers' price expectations. As in Paroush and Wolf (1989), this article models a competitive wool growing enterprise in a two period world (the beginning of the season, and the end of the season). It investigates two choices of a risk averse grower. The first choice is the quantity of wool to produce for the season and the second is the optimal amount of wool to hedge in the futures market at the beginning of the season. At the beginning of the year, these choices are made. At the end of the year the grower sells the wool in the physical (spot) market and closes out the futures market position. The complexities are added to this scenario, one by one.

The 16 versions of the model are:

1(a), (b), (c), (d). price risk only,

2(a), (b), (c), (d). price and quantity risk,

3(a), (b), (c), (d). price, quantity and basis risk, and

4(a), (b), (c), (d). price, quantity, basis risks and transaction costs,

where (a) versions include higher absolute risk aversion coefficients (ARA) and exogenous decision making on quantity of production, (b) versions include higher ARA and endogenous quantity, (c) versions include lower ARA and exogenous quantity, and (d) versions include lower ARA and endogenous quantity. For each version, the expected utility is calculated with the corresponding hedging and production levels, as well as the percentage of certainty equivalent which would be lost from a strategy of not hedging.

Expected Utility and Certainty Equivalent

Expected utility (E(U)) is the sum of all utilities weighted by their respective probability. Utility is calculated as follows:

$$U = 1 - \exp(-\lambda.\pi) \quad .... (1)$$

where π is profit for the state in question.

Profit is calculated as follows:

$$\pi = Q.P + Q_h(F\text{-}S) - (C_v + C_f) \quad .... (2)$$

where Q is total quantity, Q_h is the quantity hedged, Q_{nh} is the quantity not hedged, F is the futures price, P is the final wool spot price, and S is the settlement price.

Variable costs are given by:

$$C_v = 1.88.\ Q + 0.00008.\ Q^2$$

and C_f is fixed costs, and where total expected quantity produced:

$$Q = Q_{nh} + Q_h.$$

The certainty equivalent is the amount exchanged with certainty that makes the decision maker (wool grower in this case) indifferent between this exchange and some particular risky prospect (e.g. wool price) (Anderson *et al.* 1977). The certainty equivalent takes into account both (a) the probabilities in the risky prospect and (b) the preferences for the consequences (Anderson *et al.* 1977). It is practical to compare a certainty equivalent (CE) with the expected money value (EMV) of a prospect (Anderson *et al.* 1977). When the CE is less than the EMV, the grower is exhibiting an aversion to risk. If the grower's CE is greater than the EMV, the decision maker has a risk preference (Anderson *et al.* 1977). The risk premium of the prospect is the difference between the mean of a risky prospect and its CE (i.e., EMV - CE in the case of a money prospect). When CE = EMV (i.e., the risk premium is zero) is the rare case of indifference to risk (the grower is risk neutral) (Anderson *et al.* 1977).

In our models, the certainty equivalent is calculated as follows;

$$CE = \ln(1 - E(U))/-\lambda \text{ .... (3)},$$

where λ is the coefficient of absolute risk aversion (ARA).

Producer Price Expectations

In their analysis, Park and Antonovitz (1990) considered expectations. Arnott (1992) said that price expectations perform a major part in production decisions (Cunningham 1993). Price expectations are mentioned throughout the literature (e.g. Eales *et al.* 1990; Scandizzo *et al.* 1983; Turnovsky 1974). However the most common assumption by far is that mean of the producer's subjective price distribution corresponds to the futures price[2]. This is clearly a special case. In this study, the impacts of relaxing this assumption are investigated.

Version 1: Price Risk Only

The first model includes price risk only. We assume that prices are normally distributed. Quantity is given exogenously in Versions 1(a) and (c), while quantity is endogenous in Version's 1(b) and (d). While hedging reduces price risk, it introduces basis risk (Robison and Barry 1987). However, in these initial simple versions of the model, we assume that the basis can be predicted with certainty. This assumption is relaxed in later versions. In this scenario, the grower can sell some wool, Q_h, forward (usually after shearing) at a fixed price F. Alternatively, the grower can sell wool, Q, on the spot market at the end of the year.

The equations, (1) (2) (3), shown above are used in these scenarios, but price is risky:

$$P = \overline{P} + \varepsilon_p \text{ .... (4)}$$

[2] Unbiased prices. (Subjective) bias in the futures contract means that the individual believes there is an expected gain from selling (buying) the futures contract. Unbiasedness is where the individual's expectations can be said to agree with those of the market.

Assume that $\varepsilon_p \sim N(0,\sigma^2)$ so that risky price is normally distributed, $P \sim N(\overline{P},\sigma^2_p)$. Robison and Barry (1987) show that the optimal quantity and hedge are given by these first order conditions:

$$\partial(E(U))/\partial Q = 0 = P - C_t' - \lambda(Q - Q_h)\sigma^2) \;....\; (5)$$

$$\partial(E(U))/\partial Q_h = 0 = P - F - \lambda(Q - Q_h)\sigma^2) \;....\; (6)$$

and the solution for Q_T is found by adding these two equations, (5) (6) together:

$$F - C_T' = 0 \;...\; (7).$$

This indicates that the grower should increase or decrease wool quantity until the marginal cost of production equals the price per kilogram of wool on the futures market. This comes about because price variability, which is the only source of risk, can be eliminated with hedging. Therefore, the quantity decision is made as if the wool production is risk free. Output only depends on the forward contract price and variable costs, not on risk attitudes (Robison and Barry 1987).

Risk attitudes, however, affect the hedging decision, where a risky asset is being traded for a certain one. Solve for Q_h with the partial derivative (6):

$$Q_h = Q - ((P - F)/\lambda\sigma^2) \qquad (8)$$

Here, if the expected spot price, P, equals the futures price, F, then total output, Q_h, will be fully hedged. If P > F, then the grower will hedge less than the full wool clip (Robison and Barry 1987). The more risk averse the grower, the greater the level of hedging for a constant positive difference between P and F. Only if F exceeds the expected spot price will the risk averse grower speculate (Robison and Barry 1987).

The percentage of certainty equivalent lost from not hedging is calculated as:

$$\%\ CE\ lost = 100.(CE_h - CE_{nh})/CE_h,$$

where CE_h is the certainty equivalent when the wool was optimally hedged and CE_{nh} is the certainty equivalent received if the level of hedging is zero.

Version 2: Price Risk and Quantity Risk

This model is the same as Version 1 except that quantity is now also a risky prospect. Quantity is exogenous in versions 2(a) and 2(c) and endogenous in 2(b) and 2(d).

Models that include both price and quantity risk are common in the hedging literature (e.g. McKinnon 1967; Baesel and Grant 1982; Bray (1981); Musser *et al.* 1996; Robison and Barry 1987); Danthine (1978), Holthausen (1979), Feder *et al.* (1980)). Of these, the last three include endogenous quantity. When output levels are uncertain, decisions about wool production and hedging become more complex. Hedging reduces or eliminates price risk but cannot eliminate quantity risk. As Robison and Barry (1987) report, the inclusion of quantity risk changes the conclusions of the model. To elaborate, let input x be converted to output by the function f, with a stochastic element v, added so that output is $f(x) + v$, where v is distributed with mean zero and variance σ^2_v. Thus, the expected quantity of wool production is :

$$E\,[f(x) + v] = f(x) \qquad (9)$$

Profit is now the product of two random variables. The hedging decision concerns two risky alternatives, resulting in a portfolio-type problem (Robison and Barry 1987).

Commenting on this model, Lapan and Moschini (1994, p.471) observed that, "The impact of production risk ... occurs for two reasons. First, the orthogonal production risk reduces the optimal hedge (for $U''' > 0$), as shown by Losq (1982). Second, the correlation between yields and futures prices affects the optimal hedge. ... Even if production and price risk are independent ... the optimal hedge is reduced by production uncertainty." They noted further that "the optimal hedge is a decreasing function of R [risk aversion]. Thus, as the individual becomes more risk averse optimal futures sales decrease" (Lapan and Moschini 1994, p 471).

Version 3: Price Risk, Quantity Risk and Basis Risk

Basis risk is the variation of the difference between the futures price and the spot price faced by the wool grower who chooses to hedge using the wool futures contract. At any point in time, there may be a difference between the spot market price of wool to be hedged and the nearby futures market price. This price differential is called the contract basis (Cunningham 1993; Lubulwa *et al.* 1996). Studies of basis risk includ Danthine (1978), Holthausen (1979), Feder *et al.* (1980) Batlin (1983), Paroush and

Wolf (1986), Antonovitz and Nelson (1988), Howell (1962), and Paroush and Wolf (1989).

Following authors such as Robison and Barry (1987), Johnson (1960), Ward and Fletcher (1971), Heifner (1973), Peck (1975), and Kahl (1983), we analyse the effects of basis risk on an enterprise.

In these versions, the only change is the profit function and is calculated as follows;

$$\pi = (Q.P) + Q_h(F - S) - (C_v + C_f)$$

where P is the final wool spot price, at which the futures contract will eventually have to be settled.

For this version of the model, Lapan and Moschini (1994) estimated optimal hedge ratios ranging between 0.73 and 0.54 under CARA and normality for Iowa soybeans.

Version 4: Price Risk, Quantity Risk, Basis Risk and Futures Transaction Costs

Transaction costs in our model are represented as linear. The profit function is:

$$\pi = (Q.P) + Q_h(F-S) - (C_v + C_f) - C_t.|Q_h|$$

where, C_t is the transaction cost for taking out a futures contract, whether it is to buy or sell product. Quantity hedged is an absolute value in the equation because transaction costs are positive even if Q_h is negative.

Transaction costs have received little attention in the literature (Bond and Thompson 1985). Clearly they will discourage hedging or speculation relative to a world with costless transactions.

Numerical Assumptions

The numerical values assumed in this analysis are realistic for relatively large scale Australian wool growing and selling. The assumptions included:

(a) expected wool production (kg / year); Q or E(Q) = 32,000 (approximately 160 bales).

(b) a recent survey (Abadi, pers. comm. 1996) showed grower wool price expectations ($/kg clean weight) to range from approximately 3.00 to approximately 13.00 with a mean of approximately 7.00, therefore we assume that P or E(P) = 7.00, the initial futures price F and the futures settlement price S also have expected values of 7.00 (Wooltrak 1997).

(c) we assume that the variance of expected quantity produced E(Q) is 57,600,000, the variance of both expected price E(P) and the settlement futures price S are 0.50626, and the covariance of E(P) and S is 0.46125.

(d) transaction costs are assumed to be $50.00 (for a round turn) per futures contract (2,500 kg) taken out (Burridge, pers. comm. 1996),

(e) the coefficients of absolute risk aversion values of 5E-7, 1E-6, 2E-6 are taken as acceptable values from the literature (Bond and Wonder 1980; Bardsley and Harris 1987), and 1E-5 for comparative purposes,

(f) fixed costs are assumed to be $13,840 per grower.

Results and Discussion

The relative importance of each of the model complexities in determining the optimal hedging strategy, and the percentage of certainty equivalent lost from not hedging are investigated. We compared the results of models including or excluding price risk, quantity risk, basis risk, transaction costs, and endogenous quantity decisions over two main absolute risk aversion values, 1E-6 and 2E-6.

Optimal Hedging Ratios

Impact of model formulations and price expectations on optimal hedging ratios

The first set of optimal hedging results (Table 1) display all four model formulations when a high level of risk aversion and exogenous quantity is specified. Absolute risk aversion is 2E-6, and quantity produced is 32,000 kilograms in this case.

From Table 1, it is evident that the impact of price expectations is far greater than any other complexity of the model. A move of only $0.03 prompts a huge shift in hedging behaviour.

When quantity risk is introduced into the model the optimal hedge decreases, confirming Lapan and Moschini (1994). The addition of complexities, in general, causes a decrease in the optimal hedge. An exception to this is for transaction costs when the expected spot price is biased above the futures price. From Table 1, we can tentatively say that the addition of quantity risk has a lower impact on the optimal hedging ratio than the impact of adding basis risk or transaction costs.

When only price risk is present, and prices are unbiased, (i.e. expected spot price is equal to the futures contract price) 100 percent of production is hedged. This result is also consistent with Robison and Barry (1987), Holthausen (1979), Feder *et al.* (1980), and Lapan and Moschini (1994).

Table 1. Optimal hedging ratio (%) (Risk aversion 2E-6; exogenous quantity decision).

Model Formulation*	Mean Expected Wool Spot Price ($)		
	6.97	7.00	7.03
P	192.60	100.00	7.40
PQ	190.09	97.48	4.88
PQB	163.28	79.94	-3.42
PQBT	107.72	24.38	0.00

*P = price risk, Q = quantity risk, B = basis risk, T = transaction costs.

Impact of endogenous quantity decision on optimal hedging ratios

These model formulations shown in Table 2 are the same as in Table 1 except that the grower has an extra decision to make regarding the quantity of wool produced. The results in Table 2 clearly illustrates that the inclusion of the endogenous quantity decision has no impact on the optimal hedge if basis risk is excluded, and a very small impact when basis risk is included. The endogenous quantity decision does not appear to be a very important influence on the optimal hedging strategy. This supports the findings of Danthine (1978), Feder (1980) and Holthausen (1979).

Table 2. Optimal hedging ratio (%) (Risk aversion 2E-6; endogenous quantity decision).

Model Formulation*	Mean Expected Wool Spot Price ($)		
	6.97	7.00	7.03
P	192.60	100.00	7.40
PQ	190.09	97.48	4.88
PQB	163.55	79.93	-3.52
PQBT	107.89	24.06	0.00

*P = price risk, Q = quantity risk, B = basis risk, T = transaction costs.

Impact of risk aversion on optimal hedging ratios

The model formulations in Table 3 are the same as in Table 1 but have a lower absolute risk aversion coefficient of 1E-6. It is evident in Table 3 that in the less realistic models, the results are much more sensitive to expected price. This occurs because, here, growers are less risk averse than in Table 1 and are therefore less worried about the risks of speculating. In the most realistic model, the impact of risk aversion on optimal hedging is not great.

Table 3. Optimal hedging ratio (%) (Risk aversion 1E-6; exogenous quantity decision).

Model Formulation	Mean Expected Wool Spot Price ($)		
	6.97	7.00	7.03
P	285.22	100.00	-85.21
PQ	283.96	98.74	-86.47
PQB	247.66	80.97	-85.74
PQBT	136.53	0.00	0.00

*P = price risk, Q = quantity risk, B = basis risk, T = transaction costs.

In Table 4, the most realistic model, is taken over four levels of absolute risk aversion. The realistic range of risk aversion probably includes 5E-7, 1E-6 and 2E-6. 1E-5 is very unrealistic for most farmers (Bond and Wonder 1980; Bardsley and Harris 1987). Over the realistic range, risk aversion does have an impact, but even this very wide range of risk aversion has less impact than the very narrow range of expected price. Table 4 also shows that for unbiased price of $7.00, the optimal hedge increases as the wool grower gets more risk averse.

Table 4. Optimal hedging ratio (%) (Price, quantity, basis, transaction costs (PQBT*) model; exogenous quantity decision).

Absolute Risk Aversion	Mean Expected Wool Spot Price ($)		
	6.97	7.00	7.03
5.E-07	192.60	0.00	-29.63
1.E-06	136.53	0.00	0.00
2.E-06	107.72	24.38	0.00
1.E-05	77.53	60.82	44.10

*P = price risk, Q = quantity risk, B = basis risk, T = transaction costs.

Impact of endogenous quantity on optimal hedging ratios

Table 5 shows that in the simplest models, the inclusion of the endogenous quantity decision does have a large impact at a low coefficient of absolute risk aversion. This does not hold for the more realistic model.

Table 5. Optimal hedging ratio (%) (Risk aversion 1E-6; endogenous quantity decision).

Model Formulation*	Mean Expected Wool Spot Price ($)		
	6.97	7.00	7.03
P	470.41	100.00	-270.42
PQ	283.95	98.74	-86.47
PQB	248.02	80.97	-85.75
PQBT	136.82	0.00	0.00

*P = price risk, Q = quantity risk, B = basis risk, T = transaction costs.

Expected Cost of Not Hedging

Impact of model formulations and price expectations on cost of not hedging

In Table 6, the cost to the wool grower of not hedging is shown here and is very small. This is calculated as a percentage of certainty equivalent. In Table 6, if the usual assumption of unbiased prices is true, (i.e. expected price E(P) equals the futures contract price F) then the value of futures is very low. This is true for all of our results. The main value of futures is when E(P) < F which is when the grower is speculating. Other results not shown here indicate that if E(P) > F by enough, then the grower will also receive a large expected benefit by speculating as a wool buyer.

Including complexities does not have a big impact on the cost of not hedging, but the addition of transaction costs seems to be the most important. Adding transaction costs decreases the benefit gained from hedging which is not surprising.

The presence of the zero values when E(P) is $7.03 (Table 6) can be explained by the fact that these scenarios have correspondingly very low optimal hedging ratios (Table 1).

Table 6. Cost of not hedging (% of CE) (Risk aversion 2E-6; exogenous quantity decision).

Model Formulation*	Mean Expected Wool Spot Price ($)		
	6.97	7.00	7.03
P	2.97	0.81	0.00
PQ	3.03	0.80	0.00
PQB	2.35	0.57	0.00
PQBT	1.04	0.05	0.00

*P = price risk, Q = quantity risk, B = basis risk, T = transaction costs.

Impact of endogenous quantity decision on cost of not hedging

These results of Table 7 show that the impact of endogenous quantity is not great (Table 7). When compared to Table 6, the cost to the grower from not hedging is slightly lower when E(P) is $6.97 and $7.00. These results suggest that wool growers do slightly respond by altering the quantity produced. Generally, Table 7 results are highly consistent with Table 6 results.

Table 7. Cost of not hedging (% of CE) (Risk aversion 2E-6; endogenous quantity decision).

Model Formulation*	Mean Expected Wool Spot Price ($)		
	6.97	7.00	7.03
P	2.81	0.76	0.00
PQ	2.85	0.76	0.00
PQB	2.34	0.56	0.00
PQBT	1.03	0.05	0.00

*P = price risk, Q = quantity risk, B = basis risk, T = transaction costs.

Impact of risk aversion on cost of not hedging

The results in Table 8 show that the impact of lower risk aversion is not great (Table 8) when compared with Table 6. When compared to Table 6, the cost to the grower from not hedging is slightly higher when E(P) is $6.97 and $7.00. These results indicate that wool growers do slightly respond by speculating. Generally, Table 8 results are highly consistent with Table 6 results.

Table 8. Cost of not hedging (% of CE) (Risk aversion 1E-6; exogenous quantity decision).

Model Formulation*	Mean Expected Wool Spot Price ($)		
	6.97	7.00	7.03
P	3.24	0.40	0.29
PQ	3.28	0.40	0.30
PQB	2.63	0.28	0.31
PQBT	0.81	0.00	0.00

*P = price risk, Q = quantity risk, B = basis risk, T = transaction costs.

In Table 9, the most realistic model, PBQT, is taken over four levels of absolute risk aversion. Table 9 results show that the cost from not hedging increases as the wool grower gets more risk averse. Presumably, this result arises because, as Table 4 shows, there is more hedging taking place at the higher absolute risk aversion levels. The change in absolute risk aversion, however, does not change the cost of not hedging a great deal unless the risk aversion coefficient is unrealistically large.

Table 9. Cost of not hedging (% of CE) (Price, quantity, basis, transaction costs (PQBT*) model; exogenous quantity decision).

Absolute Risk Aversion	Mean Expected Wool Spot Price ($)		
	6.97	7.00	7.03
5.E-07	0.80	0.00	0.02
1.E-06	0.81	0.00	0.00
2.E-06	1.04	0.05	0.00
1.E-05	3.28	2.01	1.05

*P = price risk, Q = quantity risk, B = basis risk, T = transaction costs.

The expected cost of not hedging with hedging constrained to 100%

When Table 10 is compared to Table 6, the cost of not hedging is less for all model formulations and expected price combinations if the hedging is set to 100% than when it is endogenous. This means that the benefits gained from having endogenous hedging (Table 6) are less than one percent of certainty equivalent in all but one combinations (PQBT, $7.03). E(P) of $6.97 in Table 6 is based on a high level of speculation, where optimal hedging > 0. In Table 10, hedging when E(P) of $6.97 is constrained to 100%. Most of the benefits apparent in Table 6 can be obtained without hedging beyond 100%, especially in the most realistic model formulation.

Table 10. Cost of not hedging (% CE) when hedging is constrained to 100% (Risk aversion 2E-6; exogenous quantity decision).

Model Formulation*	Mean Expected Wool Spot Price ($)		
	6.97	7.00	7.03
P	2.30	0.81	-0.69
PQ	2.36	0.80	-0.76
PQB	2.01	0.53	-0.95
PQBT	1.03	-0.46	-1.95

*P = price risk; Q = quantity risk; B = basis risk; T = transaction costs.

Conclusion

This paper reports results from a range of hedging models representing realistic complexities encountered when making hedging decisions in the Australian wool industry. These complexities include price risk, production risk, basis risk, transaction costs, variation in risk attitudes, and variation in producers' price expectations. The relative importance of each of these complexities in determining the optimal hedging strategy is investigated. The results indicate the high importance of price expectations, the relative unimportance of risk aversion (in the most realistic model) as determinants of hedging decisions, and that most of the benefits of hedging can be obtained without hedging beyond 100%.

The impact of price expectations is far greater than any other complexity of the model and is evident in all of the results. For example, for the most realistic model (PQBT) with a risk aversion coefficient of 2E-6 and with exogenous quantity, a downward movement in expected price of only $0.03 prompts a shift in hedging behaviour of 83%.

In the simplest and most unrealistic model which includes price risk only and unbiased prices, 100 percent of production is hedged. This result is supported in the literature (e.g Robison and Barry 1987; Holthausen 1979; Feder *et al.* 1980; Lapan and Moschini 1994). We found, as Musser *et al.* (1996) and Lapan and Moschini (1994) did, that when production risk is included, the grower's optimal hedging level is reduced. When transaction costs are added into the model, the optimal hedge moves toward zero. This is because the presence of transaction costs lead to an increase in marginal costs and therefore, marginal benefits must move accordingly.

The inclusion of the endogenous quantity decision into the more realistic model (PQBT) has little or no impact on the optimal hedge or on the costs of not hedging and therefore does not appear to be a very important influence in the hedging model.

Throughout the results, when the most realistic model is being tested, the impact of risk aversion is not great. Over a realistic range risk aversion does have an impact, but substantially less impact than the impact of expected price. For an unbiased price of $7.00, the optimal hedge increases as the wool grower gets more risk averse. This is supported by Lapan and Moschini (1994)[3].

If the assumption of unbiased prices holds true, then the value of using futures is very low. This is true for all of our results. If the grower is willing to speculate, then futures have some value but this value does not arise from their potential to reduce risk! Most of the benefits from hedging can be obtained without hedging beyond 100%, especially in the most realistic model formulation.

In summary, we found that the most important factor affecting optimal hedging is the wool grower's price expectations. Results from a recent survey (Abadi, pers. comm. 1996) indicate that the variance of wool grower price expectations is large and so hedging behaviour for individual growers can not be easily generalised.

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[3] When they derived an exact solution for the optimal futures hedging problem under price, production, and basis uncertainty with a CARA utility function and a joint normal distribution for futures price, cash price, and yield.

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