

Willingness to Pay for Weather Derivatives by Australian Wheat Farmers¹

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Abstract

A theoretical optimal hedging model is developed to determine potential demand from Australian farmers for a hedging tool to remove the economic consequences of climate related variability in wheat yield. In the past, financial instruments have been developed to hedge price risk on capital markets; however, in more recent times new financial instruments, weather derivatives, have been developing that hedge the volumetric risk associated with unfavourable weather. Weather derivatives have the ability to effectively hedge weather related volume risk for the agricultural, mining, energy and manufacturing industries, while also providing a risk management tool for construction firms and special events organisers, although there are still many hurdles to implementing agricultural weather derivative contracts in Australia. The optimal hedging ratio is found to be quite sensitive to the degree of risk aversion of the farmer and to the cost of obtaining the contracts.

Keywords: weather derivatives, risk, hedging, wheat.

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1. Introduction

Australia is known for its vast landmass with large arid plains and its climatic contrasts and extremes. The Australian climate has an inherent variability in the weather at different spatial and temporal scales, which ensures there will always be unpredictable, extreme weather events (Paoli & Bass, 1997:1). The impact of climatic variability on Australia's national economy is the single greatest influence beyond the state of the global economy (Bureau of Meteorology, 2003:iii). Favourable weather can provide increased profits for farms, while unfavourable weather conditions can have serious adverse financial effects upon cash flow, and ultimately the viability of farms.

Weather affects demand for, and supply of, farming inputs and outputs in cropping enterprises. In Australian wheat production yield variability arises primarily from climatic risk and tends to be highly correlated across regions (Simmons & Rambaldi, 1997:157). This yield risk is a separate issue from price risk which may also be present (Yoo, 2003:1) and for which there are a variety of other hedging methods. Weather risk management aims to achieve financial protection from weather conditions that adversely affect earnings. Climate derivative instruments are designed to absorb an exact portion of weather exposure, leaving a residual risk that is commensurate with risk tolerance (Trueb, 2003:5). In the past, farmers have used a variety of risk management methods to reduce their vulnerability to both price and yield risk, generally through diversification of activities to include other commodities or through financial instruments such as insurance contracts, futures contracts, and forward contracts. However, the extent to which price and yield risk can be minimised is limited for Australian wheat farmers, especially through diversification as production of agricultural commodities on individual farms tends to be highly correlated, with adverse weather conditions affecting all output.

The worldwide development of a new financial tool called a "weather derivative" has added a new and useful method for Australian weather affected firms to hedge climatic risk. Weather derivatives are a relatively new alternative for hedging climatic risk that have the main purpose of providing the means to manage exposure to changes in weather and/or to offset the adverse effects of weather on sales, expenses and profits (Aquila, 2000; Vinning, 2000:310). These derivative contracts can be used to hedge climatic risk in the agricultural sector, as well as in the energy, manufacturing and construction sectors, which are also affected financially by adverse weather conditions. Weather derivatives provide a way of transferring risks associated with fluctuations in the weather and climatic system from firms wishing to minimise weather related risk to firms more able or willing to accept the risk (Werner, 2000). The benefit for Australian agriculture is that weather derivatives may provide some protection against weather-related changes in production by hedging the volumetric risks associated with climatic risk (Campbell & Diebold, 2002:1).

The pricing of weather derivatives differs to other, more traditional derivatives. Rather than being linked to the underlying price of an exchange-traded commodity, weather derivatives are linked to weather indices such as temperature, rainfall or frost (AFMA, 2002:5). To associate a value with these indices, a dollar amount, called the tick size, is associated with each unit in the payoff calculation (Garman, Blanco & Erickson, 2000). Most weather derivative contracts are capped at some predetermined level to reduce the risks that extreme weather would cause to writers of positions (Alaton, Djehiche & Stillberger, 2002:17). In Australian agriculture there has been a range of crop insurance type products available to farmers to hedge their grain production volume and price. Weather derivatives differ to these traditional insurance contracts in some key ways. Weather derivatives essentially eliminate the problems of adverse selection and moral hazard that so often plague insurance contracts, since payouts are based upon a weather index. Therefore, individual wheat producer's decisions do not contribute to the level of the payout and cannot affect the payout received from the contract (Mahul, 2001:597). This alleviates some of the problems for farmers associated with trying to prove that they have suffered a financial loss due to weather events. In general, insurance contracts are more suited to insuring extreme events with a low probability of occurrence, while weather derivative contracts are more suited to hedging risk associated with non-extreme events having a much higher probability of occurrence (Yoo, 2003:1).

Trade in weather derivatives began in Australia in 2000 and is still in its infancy with most of the trades undertaken by energy firms. The most recent known contract negotiated is a 5-year critical day contract for a hydroelectric firm. In 2002 it was estimated that over 25 'deals' had been undertaken by Australian counterparties and the average nominal value (value of risk transferred) in these trades has been A\$1m (AFMA, 2002:3). The market in Australia is less advanced than the respective weather derivative markets in Europe and America. In Australia the weather options are held to maturity with a cash settlement occurring the day following the completion of the option since there are no secondary markets allowing closure of positions. This obviously has implications for the premium level of the contracts, as underwriters are unable to pass on the absorbed risk through a secondary market.

In section 2 a theoretical model of an optimal hedging rule has been developed for Australian wheat producers. This model is based upon the model used by Simmons & Rambaldi (1997), however, it has been modified to include a derivative instrument that allows a farmer to protect a proportion of his or her yield from climatic factors using an optimal hedging rule derived endogenously with the production decision. Section 3 contains an empirical analysis of the Australian wheat industry based on the model to identify in money terms the farmer's interest in reducing yield variability from climate factors through these derivative instruments. The values of the coefficients in the empirical analysis are from previously published empirical work and from direct estimation based on Australian Bureau of Agriculture and Resource Economics (ABARE) data. Section 4 discusses conclusions obtained from the model.

2. Theoretical Model

Wheat growers' expected utility is described using the weighted sum of expected value of and unanticipated variation in wheat profits. Let $E(U)$ be expected utility, $E(\pi)$ be expected profit and k the Pratt (1964) coefficient of absolute risk aversion. Expected utility is:

$$E(U) = E(\pi) - \frac{k}{2} E[(\pi - E(\pi))^2]. \quad (1)$$

This function is a member of a general class (E-V or mean-variance) of utility functions. Unlike other E-V formulations the version here is Constant Absolute Risk Aversion (CARA) which is more desirable than the quadratic utility specification discussed by Anderson, Dillon & Hardaker (1997:89-90) which implies Increasing Absolute Risk Aversion (IARA). CARA occurs in this specification because the risk premium $-\frac{k}{2} E[(\pi - E(\pi))^2]$ is independent of wealth (Rambaldi & Simmons, 2000:347).

Production occurs within a one-year cycle where producers maximise utility in period t conditional on information available in period $t-1$:

$$E_{t-1}(U_t) = E_{t-1}(\pi_t) - \frac{k}{2} E_{t-1}[(\pi_t - E_{t-1}(\pi_t))^2]. \quad (2)$$

Prices follow a naïve expectations model with a multiplicative error term where u_{1t} is a normal random variable with zero mean and variance σ_1^2 :

$$p_t = p_{t-1}(1 + u_{1t}). \quad (3)$$

Realised production in period t is:

$$q_t = A_t Y_t \quad (4)$$

where A_t is area sown in $t-1$ resulting in area of wheat in period t and Y_t is yield per hectare. The equation for yield, 5, incorporates a trend component as well as a multiplicative error term. The trend component (T) reflects technological improvements in crop husbandry and production over time such that d is mean yield and u_{2t} is a random variable with zero mean and variance σ_2^2 . So yield in period t is mean yield across the sample plus the trend component, multiplied by disturbance:

$$Y_t = (d + eT)(1 + u_{2t}). \quad (5)$$

By world standards, Australia is a relatively small producer of grain, with wheat accounting for around 3% of annual world production (AWB, 2003). Even though Australia exports a large percentage of this wheat, Australians supply only a small fraction of the world wheat market and so are effectively price takers both individually and collectively. Thus u_{1t} and u_{2t} are assumed to be independent so $E_{t-1}(u_{1t}u_{2t}) = 0$. This implies the expected values of both u_{1t} and u_{2t} are zero and their covariance is zero and, by implication, p_t and q_t are also independent. It is conceded that in some specialist wheat markets Australia may be able to affect prices.

Since A_t is known in period $t-1$ it follows planned production is:

$$q_t^e = A_t(d + eT) \quad (6)$$

and realised production is:

$$q_t = A_t(d + eT)(1 + u_{2t}). \quad (7)$$

Assuming costs are a quadratic function of production it follows profit in period t without hedging is:

$$\pi_t = p_{t-1}(1 + u_{1t})q_t^e(1 + u_{2t}) - a - bq_t^e - cq_t^{e^2} \quad (8)$$

and, where h is the proportion of u_{2t} (yield risk) that a farmer chooses to eliminate and m is the price of doing so, profit in period t with hedging becomes:

$$\pi_t^h = p_{t-1}(1 + u_{1t})q_t^e(1 + (1 - h)u_{2t}) - hm - a - bq_t^e - cq_t^{e^2}. \quad (9)$$

Thus, wheat profits equal revenue including the payout from the weather instrument minus expected costs of production, minus the hedge premium. Two simplifying assumptions have been made about costs to arrive at 8 and 9. The first simplification is there is no cost savings from a failed crop. This can be justified in Australian broadacre cropping systems because low yielding sparse or weedy crops may be just as costly to harvest as high yielding, evenly spaced crops. Second, the quadratic functional form can be viewed as a second order approximation to any higher order differentiable cost function.

Conditional expected profits become:

$$E_{t-1}(\pi_t^h) = p_{t-1}q_t^e - hm - a - bq_t^e - cq_t^{e^2}. \quad (10)$$

Conditional expected utility is found by substituting 9 and 10 into 2, simplifying and taking expectations conditional on information available at $t-1$:

$$\begin{aligned} E_{t-1}(U_t) &= p_{t-1}q_t^e - hm - a - bq_t^e - cq_t^{e^2} \\ &- \frac{k}{2} \left[\left(E_{t-1} \left(p_{t-1}(1 + u_{1t})q_t^e(1 + (1 - h)u_{2t}) - hm - a - bq_t^e - cq_t^{e^2} \right) \right)^2 \right. \\ &\quad \left. - \left(p_{t-1}q_t^e - hm - a - bq_t^e - cq_t^{e^2} \right)^2 \right] \\ &= p_{t-1}q_t^e - hm - a - bq_t^e - cq_t^{e^2} - \frac{k}{2} \left[E_{t-1} \left(p_{t-1}(1 + u_{1t})q_t^e(1 + (1 - h)u_{2t}) - p_{t-1}q_t^e \right)^2 \right] \\ &= p_{t-1}q_t^e - hm - a - bq_t^e - cq_t^{e^2} \\ &\quad - \frac{k}{2} p_{t-1}^2 q_t^{e^2} E_{t-1} \left(u_{1t}^2 + u_{2t}^2 + u_{1t}^2 u_{2t}^2 - 2hu_{2t}^2 - 2hu_{1t}^2 u_{2t}^2 + h^2 u_{2t}^2 + h^2 u_{1t}^2 u_{2t}^2 \right) \end{aligned} \quad (11)$$

First Order Conditions are obtained by differentiating expected utility with respect to planned production, q_t^e , and with respect to the amount of hedging, h , respectively:

$$\frac{\delta E_{t-1}(U_t)}{\delta q_t^e} = p_{t-1} - b - 2cq_t^e \quad (12)$$

$$-kq_t^e p_{t-1}^2 E_{t-1} \left(u_{1t}^2 + u_{2t}^2 + u_{1t}^2 u_{2t}^2 - 2hu_{2t}^2 - 2hu_{1t}^2 u_{2t}^2 + h^2 u_{2t}^2 + h^2 u_{1t}^2 u_{2t}^2 \right) = 0$$

$$\frac{\delta E_{t-1}(U_t)}{\delta h} = -m - kp_{t-1}^2 q_t^{e^2} E_{t-1} \left(-2u_{2t}^2 - 2u_{1t}^2 u_{2t}^2 + 2hu_{2t}^2 + 2hu_{1t}^2 u_{2t}^2 \right) = 0. \quad (13)$$

These two first order conditions can be solved simultaneously to find expressions for planned production, q_t^e , and for h . Solving them individually could result in simultaneity bias (Kahl, 1983) so the model was solved both separately and simultaneously to understand the differences arising from the two solution techniques.

3. Empirical Results

The model was first specified without any hedging using elasticities from previous studies to obtain parameters useful for simulation. Profit was found from 8, which is re-written below and conditional expected profits are shown in 15:

$$\pi_t = p_{t-1}(1 + u_{1t})q_t^e(1 + u_{2t}) - a - bq_t^e - cq_t^{e^2} \quad (14)$$

$$E_{t-1}(\pi_t) = p_{t-1}q_t^e - a - bq_t^e - cq_t^{e^2}. \quad (15)$$

Substituting 14 and 15 into 2, conditional expected utility is:

$$E_{t-1}(U_t) = p_{t-1}q_t^e - a - bq_t^e - cq_t^{e^2} - \frac{k}{2}p_{t-1}^2q_t^{e^2}E_{t-1}(u_{1t}^2 + u_{2t}^2 + u_{1t}^2u_{2t}^2). \quad (16)$$

This was maximised with respect to the decision variable, planned production q_t^e :

$$\frac{\delta E_{t-1}(U_t)}{\delta q_t^e} = p_{t-1} - b - q_t^e(2c + kp_{t-1}^2E_{t-1}[u_{1t}^2 + u_{2t}^2 + u_{1t}^2u_{2t}^2]) = 0 \quad (17)$$

which was then solved for planned production:

$$q_t^e = \frac{-b + p_{t-1}}{2c + kp_{t-1}^2E_{t-1}(u_{1t}^2 + u_{2t}^2 + u_{1t}^2u_{2t}^2)}. \quad (18)$$

An increase in price increases the level of planned production, while an increase in associated yield or price risk decreases the level of planned production. Planned production is decreased by larger values of k , the coefficient of absolute risk-aversion, while if the farmer is risk-neutral increases in risk have no effect on farmers' production decisions.

The next step is to solve for the model parameters using the dataset. In this case, mean values of price, area, yield and volume for the 5 year period 1997-98 to 2001-02 (with prices inflated to 1989-90 levels using the Consumer Price Index) were calculated using data from the Australian government's agricultural economics research agency, the Australian Bureau of Agricultural and Resource Economics (ABARE 2002). These mean values are shown in Table 1 as P_{t-1} , A_t , Y_t and Q_t .

Table 1: Mean values of model variables

Variable	Mean Value
P_{t-1}	\$223/tonne
A_t	11,578 ('000 hectares)
Y_t	1.938 (t/ha)
Q_t	22,481 (kilo tonnes)
σ_1^2	0.0332
σ_2^2	0.0329

The values of σ_1^2 and σ_2^2 in Table 1 were calculated using deflated price and yield data from 1955-56 to 2001-02 obtained from ABARE (1995, 2002). The value of σ_1^2 was obtained from 3 using a spreadsheet and the coefficients d and e in 5 were estimated using regression analysis with a single explanatory variable, trend (T):

$$Y_t = d + eTrend(1 + u_{2t}) \quad (19)$$

The value of σ_2^2 was obtained from 7 using a spreadsheet and estimated parameters d and e (see Table 2).

Table 2: Model parameters

Coefficient	Value
b	148.67
c	0.0081
d	0.9706
e	0.0155
k	9.633E-8

The value for k (see Table 2) was obtained after some manipulation from the estimate of the coefficient of absolute risk aversion from Bond and Wonder (1980) using the technique described in Simmons and Rambaldi (1997:164). k turned out to be 9.633E-8 and corresponded to a coefficient of relative risk aversion of 0.265. To calculate b and c an elasticity of supply with respect to prices is needed, along with the coefficient of absolute risk aversion and the values of the other variables. The own-price elasticity of supply was obtained from Simmons and Rambaldi (1997:164) who averaged a range of previously published estimates to arrive at an elasticity of 0.60. To obtain b and c , the elasticity of supply was incorporated into 18 along with values of the other parameters. Equation (18) became:

$$q_t^e = \alpha + \beta p_{t-1} \quad (20)$$

where
$$\alpha = \frac{-b}{2c + kp_{t-1}^2 E_{t-1}(u_{1t}^2 + u_{2t}^2 + u_{1t}^2 u_{2t}^2)} \quad (21)$$

and
$$\beta = \frac{1}{2c + kp_{t-1}^2 E_{t-1}(u_{1t}^2 + u_{2t}^2 + u_{1t}^2 u_{2t}^2)} \quad (22)$$

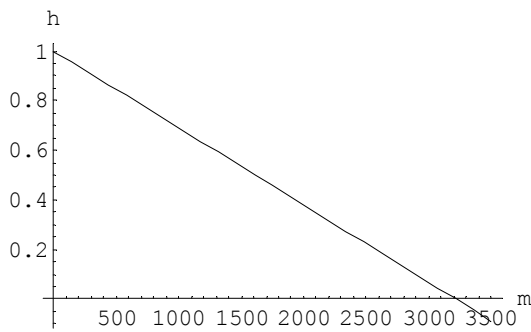
The values of α and β were obtained from 20 through algebraic manipulations and utilisation of the value for the elasticity of supply as well as the mean price and quantity. These values were used in 22 with the coefficient of absolute risk aversion and values of the variables to calculate c . Coefficient b was obtained as a residual using 21. These coefficients and variable values were then used to solve for planned production, q_t^e , and the hedging ratio, h . From 12 and 13 and calculated values for variables and coefficients the First Order Conditions are:

$$\frac{\delta E_{t-1}(U_t)}{\delta q_t^e} = 74.33 - 0.0165362q_t^e + 0.000317929hq_t^e - 0.000158964h^2q_t^e = 0 \quad (23)$$

$$\frac{\delta E_{t-1}(U_t)}{\delta h} = -m + 0.000158964q_t^{e^2} - 0.000158964hq_t^{e^2} = 0 \quad (24)$$

These expressions were first solved individually for planned production, q_t^e and the amount of hedging, h respectively, with a range of values for m , the price of the hedge for the industry as a whole. The expressions are solved with m taking a range of values from zero to \$3.5m, which results in a range of hedging points that are graphed in Figure 1a. The First Order Conditions were then solved simultaneously, using the same range for m with results reported in Figure 1b.

a) Solved individually



b) Solved simultaneously

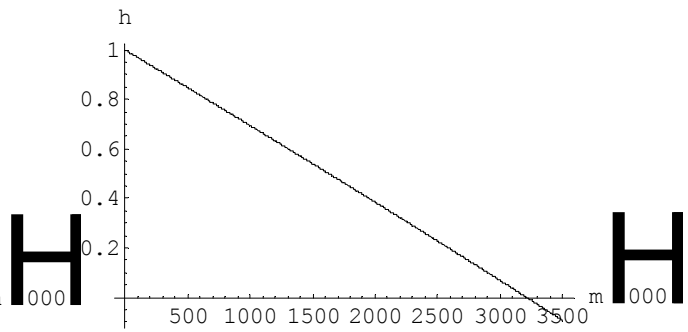


Figure 1a & 1b: Optimal hedging ratios for a range of hedging prices

Figures 1a and 1b show the optimal hedging ratios for a range of hedging prices and can be viewed as marginal value curves for the hedging instrument. As the two figures show, the results are essentially the same indicating simultaneity bias is not a significant factor in solving the model for these coefficient values. As shown in Figures 1a and 1b, the optimal hedge ratio approaches zero as the industry price for the hedging approaches \$3.2million (in today's prices) indicating demand for this type of hedging across the industry is likely to be very low. However, some farmers will operate in more risky circumstances so still may demand significant amounts of this type of hedging product. There has been some discussion about the value of the coefficient of absolute risk aversion derived by Bond and Wonder (1980) and used in Simmons and Rambaldi (1997) since it is much lower than previous expectations of its value. It has also been found that in developing countries the level of risk aversion is much higher than the value utilised in this study. Therefore, sensitivity analysis was undertaken to evaluate the effects of greater risk aversion among farmers on the results. The coefficient of absolute risk aversion was increased by a factor of ten to become 9.633E-7 and the model re-run *ceteris paribus*.

a) Solved individually

b) Solved simultaneously

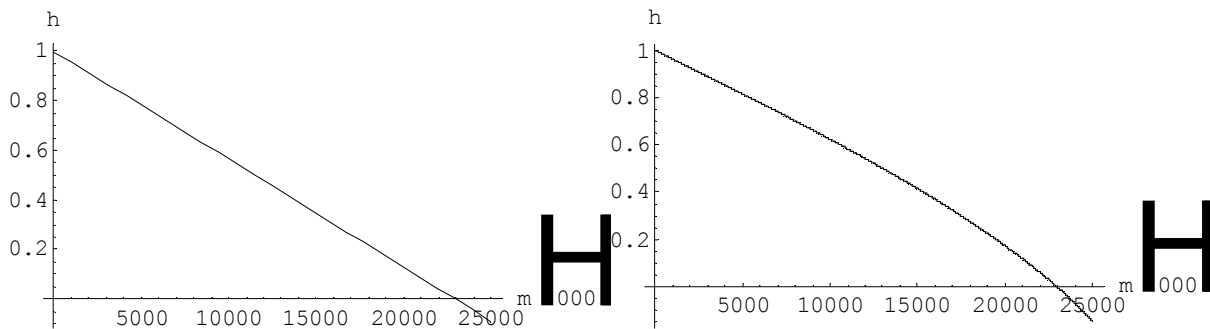


Figure 2a & 2b: Optimal hedging ratios for a range of hedging prices with increased risk aversion

The sensitivity analysis on k has shown first that farmers are much more willing to pay for climatic hedging products as their level of risk aversion increases, and second, it appears simultaneity bias in the results becomes more of an issue at higher values of the coefficient of risk aversion. Increasing k to 9.633E-7 with the model coefficients remaining constant resulted in farmers being willing to pay for climatic hedging products until their price, m , approaches \$23million rather than only \$3.2 previously.

4. Conclusions

The results show that under our assumptions about farmer's preferences and technology, there is a potential but small demand by Australian wheat farmers for climatic hedging tools. However, this result must be considered with some degree of caution. The results are sensitive to the degree of risk aversion and thus the baseline assumption about this value originally derived from work by Bond and Wonder (1980) underpin the magnitude of the results. The results are also sensitive to the elasticity of supply since its value determines the model coefficients, b and c . Also, of course, it has been assumed that underwriters in Australia would be willing to provide appropriate climatic instruments. The results presented here are preliminary as the work is ongoing. In future research model coefficients will be estimated to remove dependence on the previously estimated measure of the supply elasticity used in this study and a "Burn analysis" pricing model is being developed to measure the willingness of underwriters to provide climatic hedging products for agricultural enterprises in Australia.

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