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Elicitation of irrigators' risk preferences from observed behaviour*

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Water trading in the Murray–Darling Basin of Australia has developed to the point where it is a common adaptation tool used by irrigators, making it an apt case study to elicit the marginal value of irrigation water and irrigators' risk preferences in two key industries with differing levels of water dependence. Our data come from large-scale and representative surveys of irrigated broadacre and horticultural farms in the Murray–Darling Basin over a 6-year period. The marginal contribution of irrigation water to profit is estimated at \$547 and \$61/ML on average in horticulture and broadacre, respectively. Horticultural irrigators are found to be averse to the risk of large losses (downside risk) while broadacre irrigators are averse to the variability (variance) of profit.

Key words: irrigation, marginal value of water, Murray–Darling Basin, profit function, risk preferences.

1. Introduction

Farmers are exposed to a large number of risks and uncertainties in their everyday life, such as prices, production, health, technology, legislation, marketing and weather. Australian farmers are probably unique in the developed world in regard to their ranking of relative risks (Nguyen *et al.* 2007). Weather focuses much more predominantly in Australian risk ratings than in other developed countries. Among other examples, price or marketing risks were perceived as the most important source of risk by Dutch farmers (Meuwissen 2001), New Zealand farmers named marketing risks (Martin 1996) and American farmers named crop price and yield variability (Hall *et al.* 2003). This study focuses on uncertainty related to future weather and the risk of insufficient water facing irrigated farms in the Murray–Darling Basin (MDB) of Australia. In this region, irrigators have the possibility to buy and sell water.

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Irrigation water markets have two desirable properties. First, they allow for a more efficient allocation of water among competing uses in times of water scarcity. Second, they offer water users with varying risk preferences the possibility of managing the risk of water shortage by allowing them to trade water. Empirical studies of the relationship between farmers' risk preferences and their trading decisions on water markets using real data are rare, mainly because of the lack of widespread water markets across the world, but also because of the lack of public access to data. Recent analyses using farm survey data and assuming risk averse irrigators include Cristi (2007) on Chile and Zuo *et al.* (2015a) on Australia. Cristi (2007) used a consumption-based asset-pricing model to study farmers' trading decisions, with their preferences characterised by a Constant Absolute Risk Aversion (CARA) utility function. Zuo *et al.* (2015a) did not specify a utility function but assumed that irrigators were risk averse and tested whether irrigators who were more exposed to risk (as measured by variability in their profit) traded higher volumes on water markets (results found irrigators purchased more water allocations).

This study does not make any a priori assumptions on the form of irrigators' risk preferences (in other words whether they are risk averse or risk loving) and instead seeks to elicit risk preferences from farm survey data using the theoretical framework in Calatrava Leyva and Garrido (2006). These authors developed a model of irrigators' profit maximisation in the presence of water markets when both the level of water allocations and the price of water were uncertain.

Under the assumption that irrigators maximise the expected utility of their profit, but without any a priori assumption on the form of their utility function, the first-order condition describing irrigators' optimal choice in terms of irrigation water use can be derived. Under risk neutrality, the first-order condition states that the marginal gain in profit from the optimal quantity of irrigation water used on the farm is equal to the expected water price. For a non-risk neutral farmer, an extra term that includes two unknown factors enters the optimal condition and these two factors characterise an irrigator's risk preferences. This condition is assumed to hold for our sample and the optimality condition using panel data for irrigated farms operating in the MDB is estimated. More precisely, whether irrigators are risk averse or risk lovers can be identified.

Second, it is tested whether the risk premium (whether positive or negative) is driven by the variability in profit (moment of order two or variance) or the probability of very bad outcomes in terms of profit realisation (moment of order three or skewness of the profit distribution), or both. The estimation of the first-order condition requires making assumptions on irrigators' expectations in terms of the level of water allocations and water prices in the coming year. Different expectation models are tested, with the one that provides the best fit chosen.

The analysis is based on data for MDB irrigating farms over the seasons 2006–2007 to 2011–2012. The analysis is conducted separately for the horticulture and broadacre sectors. These two industry sectors were chosen as they represent two differing forms of production. For example, horticultural producers have permanent plantings and need a minimal amount of water annually to protect long-term investments, while broadacre industries have annual plantings and more flexible production which can be adjusted seasonally in response to water scarcity issues. As such this study provides estimates of the value of irrigation water as well as evidence on Australian irrigators' risk preferences. The findings also provide insight into the way irrigators form expectations on future water allocations and prices. Such an understanding of irrigator risk preferences and their risk management decisions to deal with uncertain situations is important for government policy related to the design of water markets but more broadly to income and drought support, and other exit package strategies.

2. Literature review

2.1 Farmers' risk preferences

Many methods have been used to measure individual risk preferences. For example, using experimental procedures with hypothetical questions (e.g. using lottery questions or gambling tasks); inference from actual farm actions; direct elicitation of utility functions (e.g. risk aversion is a property of the utility function and can be measured through the income elasticity of marginal utility); and through psychological survey questions (e.g. measuring risk attitudes through psychological scales). Much of the empirical literature has suggested that farmers are risk averse in most situations (Saha *et al*. 1994; Kim and Chavas 2003; Pope *et al*. 2011; Reynaud and Couture 2012).

Farming in the Australian context is highly risky, and the biggest risks include production and price risks. At the same time, there are only a few market-based tools Australian farmers can adopt to insure themselves against risk. For example, broadacre crops can be insured against hail and fire damage but not crop loss due to drought, flood or frost (Khuu and Weber 2013).

There is some historical evidence to suggest Australian farmers are risk averse in general. Both for-and-against evidence includes Francisco and Anderson (1972) who found evidence of both risk loving and risk aversion among pastoral farmers in New South Wales (NSW). Using questions on probabilities and outcomes, Bond and Wonder (1980) surveyed 201 Australian farmers and found a moderate degree of risk aversion. Bardsley and Harris (1987) used time-series cross-sectional data from Australian broadacre agriculture to estimate farmers' risk aversion coefficients and found evidence of risk aversion, with it decreasing with wealth and increasing with income. Ghadim and Pannell (2003) surveyed Western Australian (WA) farmers in the mid-1990s and found the majority were risk averse. Khuu and Weber (2013) also found WA farmers to be moderately strongly risk averse. Our study adds to the literature by assessing the form of irrigators' risk preferences (whether risk lovers or risk averse) from the direct observation of irrigation choices and water trading decisions in the MDB.

2.2 Farmers' expectations

This study also provides insights on irrigators' expectations about water allocations and prices. Expectations can be formed in a variety of ways, and Chavas (1999) outlines four types: (i) naïve (future expected values being set equal to the latest observation of the corresponding variable); (ii) adaptive (revised over time proportionally to the latest prediction error); (iii) quasi-rational (using predicted values from time-series models of the variable); and (iv) rational (using anticipated supply/demand market conditions).

There is no consensus on which form of price expectation farmers primarily rely on to make price predictions. Fisher and Tanner (1978) used an experimental approach with 55 Australian wheat growers to determine the methods farmers used to predict future prices. The adaptive expectations model fit the data best, and farmers indicated that the best strategy was to take an arithmetic average of past prices. Shideed and White (1989) compared six acreage response models for corn and soya beans using various price expectation hypotheses. The results suggested that no unique form of price expectation appeared as the best for both commodities. Irwin and Thraen (1994) also concluded that there was no consensus regarding the verification or falsification of the rational expectation formulation in agricultural markets after reviewing numerous studies. A striking example in this review was the diversity of results found in the structural econometric studies of the soya bean market: depending on the study reviewed, soya bean producers have naïve expectations, adaptive expectations, perfect foresight or rational expectations. The explanations offered for the divergent results are small sample sizes, lower power of statistical tests in the presence of alternative expectations and variability in specifications of the econometric models. Chavas (1999) investigated US farmers' expectations of pork prices and found that the majority of farmers (73%) used quasi-rational expectations, then rational (20%) and naïve expectations (7%).

3. Theoretical framework

This study adopts Calatrava Leyva and Garrido's (2006) theoretical framework by considering an irrigator who uses irrigation water as an input, owns some water entitlements and is able to trade them on a market. A denotes the total amount of seasonal water allocations granted to the irrigator over the year and w the irrigation water quantity used in production. Other inputs (e.g. labour, pesticides and fertilisers) are gathered in vector x.

For simplicity, it is assumed that the irrigator does not, or cannot, store water from one period to the other.[1] Hence if $w < A$, the irrigator will sell surplus water $(A - w)$ on the market. If $w > A$, the farmer will buy $(w - A)$ from the market. Water is traded at price p_w. The irrigator's profit function is thus written as:

$$\pi(w, x) = p_q f(w, x) - r'z + p_w(A - w) \tag{1}$$

where p_q is the output price, $f(.)$ the production function and r the input price vector. We assume uncertainty in the quantity of water allocations that will be available over the year (A) and in the water allocation (temporary) price (p_w).

Following Calatrava Leyva and Garrido (2006), the corresponding *restricted profit function* is where all inputs except water are assumed to be optimally chosen. By doing so, the irrigator's maximisation problem reduces to maximising the (restricted) profit over irrigation water only:

$$\mathrm{Max}_w \pi_r(w) = \pi(w) + p_w(A - w) \tag{2}$$

where $\pi(w) = \{\max_x pf(w, x) - r'x / \forall w\}$.

For a risk neutral producer who maximises expected profit, this implies the following optimality condition:

$$\pi'(w) = E(p_w). \tag{3}$$

So a risk neutral producer chooses w such that the marginal gain in profit equals the expected water price. A non-risk neutral producer maximises the expected utility of profit. Under the assumption of uncertainty in both allocations (A) and water price (p_w), the optimality condition is:

$$\pi'(w) \underbrace{-2(w - E(A))REDQ \cdot V(p_w) + 3(w - E(A))^2 MSQ \cdot M_3(p_w)}_{\text{extra term induced by non-risk neutrality}} = E(p_w) \tag{4}$$

where $V(.)$ and $M_3(.)$ are the variance and third-order moment of the water price distribution, respectively,[2] and *REDQ* (Risk Evaluation Differential Quotient) and *MSQ* (Marginal Skewness Quotient) are defined as:

[1] Carry-over rules and use vary both seasonally and spatially across MDB regions. Carry-over is often not available, or if it is available, not always used. In addition, the information available on irrigators' carry-over in the survey data was less than optimal and often missing, which when coupled with the difficulty of including carry-over in the profit functions, lead to its exclusion.

[2] The third moment (also called skewness when normalised) measures the asymmetry of a distribution. The skewness is zero for a symmetric distribution, negative when the distribution is skewed to the left (i.e. the tail of the distribution is longer on the left and there is a higher probability of getting low values) and positive when it is skewed to the right.

$$REDQ = -\frac{\partial U/\partial V(\pi)}{\partial U/\partial E(\pi)} \quad \text{and} \quad MSQ = -\frac{\partial U/\partial M_3(\pi)}{\partial U/\partial E(\pi)}$$

In the above, $U(.)$ represents an irrigator's utility function. The assumption that irrigators are non-risk neutral leads to an extra term entering the optimality condition. *REDQ* and *MSQ* are the (unknown) parameters of interest since they characterise irrigators' risk preferences. *REDQ* can be seen as the rate of substitution between the mean and variance (of profit). Utility of a risk averse irrigator increases with mean profit and decreases with profit variance, so a risk averse irrigator is willing to pay for a decrease in profit variance. The price she is willing to pay is measured by *REDQ* in terms of foregone mean profit. So the higher *REDQ*, the more an irrigator is risk averse. Similarly, *MSQ* measures the trade-off between the mean and the third moment of profit. The utility of a risk averse irrigator increases with the third moment (since the higher the third moment, the lower the probability of occurrence of low profits) so *MSQ* is negative for a risk averse irrigator, and the lower *MSQ*, the more averse the irrigator is to downside risk.

To further illustrate the relationship between an irrigator's risk preferences and his choice of the optimal quantity of water (w) is discussed in the simple case of $MSQ = 0$ (i.e. the moment of order three does not influence an irrigator's decisions). If $MSQ = 0$, we have:

$$\pi'(w) - 2(w - E(A))REDQ \cdot V(p_w) = E(p_w), \tag{5}$$

which is equivalent to:

$$REDQ = \frac{\pi'(w) - E(p_w)}{2(w - E(A)) \cdot V(p_w)} \tag{6}$$

If the irrigator is using more water (w) than her expected allocation ($E(A)$), she positions herself as a buyer. In this case $w - E(A) > 0$ and the denominator is positive (since water price variance is always positive). If the irrigator is risk averse, $REDQ > 0$ and hence the numerator in (6) $[\pi'(w) - E(p_w)]$ has to be positive. The profit function is commonly assumed twice differentiable, with $\pi'(w) > 0$ and $\pi''(w) < 0$, that is irrigation water has a positive but decreasing marginal contribution to profit. This is equivalent to $\pi'(w)$ being a decreasing function of w. So if $\pi'(w) > E(p_w)$ is observed, it implies that the amount of water chosen by the irrigator under uncertainty is lower than the water quantity chosen under certainty. So in this case (buyer position), uncertainty (and risk aversion) leads the irrigator to use less water than he would use under certainty.

Conversely, if the irrigator decides to use less water than her expected allocation ($E(A)$), she positions herself as a seller. In this case $w - E(A) < 0$ so the denominator in (6) is negative. If the irrigator is risk averse, $REDQ > 0$

and hence the numerator in (6) $\pi'(w) - E(p_w)$ is negative. From the profit function properties, $\pi'(w) < E(p_w)$ implies that the quantity of water chosen by the irrigator is higher than the quantity used under certainty. So in this case (the seller position), uncertainty (and risk aversion) leads the irrigator to use more water than under certainty. If the irrigator is a risk lover ($REDQ < 0$), the findings are reversed.

Under the assumption that the theoretical model is valid, the optimality condition described in (4) should hold for irrigators active in the market. In the following we estimate condition (4) using MDB irrigated farm panel data.

4. Empirical analysis

4.1 Background and data

The data used in the analysis were collected by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) in six surveys across the MDB from 2006–2007 to 2011–2012. Located in south-eastern Australia across five jurisdictions (Queensland, New South Wales, Australian Capital Territory, Victoria and South Australia), the MDB has the largest amount of irrigated agricultural land and uses more than half of the irrigation water in Australia. Irrigation water in the MDB is primarily used for horticultural crops, pasture and broadacre crops (ABS 2013). Agricultural access to water in MDB is highly variable within and between years, with a number of notable droughts over the last 120 years (Crase 2008). The most recent Millennium drought lasted over a decade and ended in 2009. Uncertainty on irrigation water availability has been a major risk management area for farmers in the MDB and water trade is one of the tools to manage such risk (Zuo *et al.* 2015a). Wheeler *et al.* (2014a) estimated that up to 86% of NSW irrigators, 77% of Victorian irrigators and 63% of South Australian irrigators had engaged in at least one water trade by 2010–2011. Two main types of water can be traded in the MDB: water entitlements (the ownership of the right to a perpetual entitlement to exclusive access of a share of water from a specified consumptive pool) and water allocations (ownership of the right to a specific volume of water allocated in a given season). Opening water allocations as a percentage of an irrigator's full entitlement are announced at the start of each season and subsequently revised throughout the season depending on storages and rainfall in catchment areas.

Figure 1 displays the monthly water market prices and allocation levels in the most active water trading zone (Greater Goulburn) in the largest irrigation district in the MDB, the Goulburn–Murray Irrigation District in Victoria from 2006–2007 to 2011–2012. Considerable variations in water prices and allocation levels were observed during this period. For example, monthly mean prices of water allocations almost reached \$1000/ML during 2007–2008 when drought was most severe; falling to as low as \$10/ML after flooding in 2010–2011.

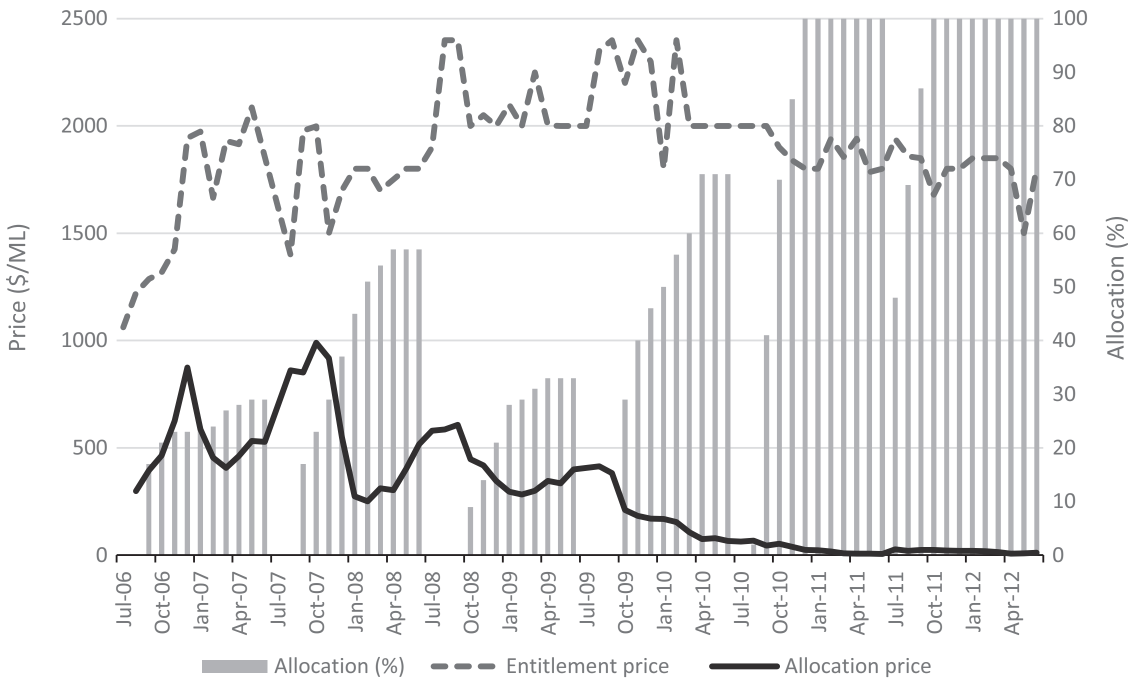

Figure 1 Monthly water allocation/entitlement prices ($/ML) and allocation levels (per cent) in the Goulburn–Murray Irrigation District from 2006–2007 to 2011–2012. Source: Watermove for 2006–2007 and Victoria Water Register for 2007–2008 to 2011–2012.

ABARES irrigation surveys are conducted via face-to-face interviews and information collected includes farm physical and financial variables, input and output variables and water trade variables. The survey is a rotating (unbalanced) panel, with some farms randomly dropped after 3 years. Each farm is classified into one industry based on its largest receipts; hence may still produce commodities from different industries.

There is a significant difference between horticulture and broadacre in their dependence on irrigation water and the value for each water unit in their production. The demand for water in horticultural production is generally more inelastic relative to broadacre production such as pasture and rice (Zuo *et al.* 2015b). This result reflects the fact that broadacre use of irrigation water is more flexible (e.g., broadacre farmers can seasonally choose to not produce and sell their water allocations) versus horticultural crops that are of higher value and more permanent. Wheeler *et al.* (2014b) also found that the value of foregone production (and additional production) from one unit of water sale (purchase) is the highest for horticulture and lowest for broadacre, which is another reason why this study chose horticulture and broadacre as key industries to investigate further. However, we also sought to analyse the other largest irrigation sector, irrigated dairy, to compare its findings with other sectors.

Table 1 presents the survey's summary statistics. On average, horticultural farms in the MDB have a smaller irrigated area than broadacre and use less irrigation water. Horticultural farms have a higher farm cash income on average than broadacre farms. Overall, horticultural irrigators are more

Table 1 Descriptive statistics

	Horticulture			Broadacre		
	Observations	Mean	Standard deviation	Observations	Mean	Standard deviation
Irrigated area (ha)	1,348	79.2	197.1	758	181.3	441.3
Farm net cash income ($)	1,348	117,970	683,742	758	98,623	339,697
Water use (ML)	1,348	454.3	1,146.3	758	655.5	1,642.1
Water allocation buyer (%)	1,348	38	49	758	17	38
2006–2007	312	30	46	128	27	44
2007–2008	310	64	48	129	13	34
2008–2009	208	58	49	127	13	34
2009–2010	176	41	49	138	17	38
2010–2011	178	9	29	117	12	33
2011–2012	164	9	29	119	22	41
Water allocation seller (%)	1,348	16	37	758	28	45
2006–2007	312	25	44	128	16	37
2007–2008	310	15	35	129	43	50
2008–2009	208	16	37	127	55	50
2009–2010	176	13	34	138	33	47
2010–2011	178	10	29	117	9	28
2011–2012	164	12	32	119	11	31

likely to be a water allocation buyer while less likely to be a seller, particularly during 2006–2007 to 2009–2010 when the MDB was in drought. After the drought ended, the proportion of horticultural irrigators buying water, and broadacre irrigators selling water, decreased significantly.

4.2 Estimation methodology

This study's purpose was to identify irrigators' risk preferences through the estimation of the *REDQ* and *MSQ* terms in Equation (4), for example:

$$\pi'(w) - 2(w - E(A))REDQ \cdot V(p_w) + 3(w - E(A))^2 MSQ \cdot M_3(p_w) = E(p_w).$$

Estimation of this equation requires preliminary estimates of some components of the equation as well as assumptions on the way irrigators form expectations on future water allocations and prices. We discuss each of the above equation terms below:

- $\pi'(w)$, the marginal contribution of water to profit, is calculated from the profit function estimation. Profit (or farm net cash income) is specified as a function of the quantity of water used over the year (w) along with other relevant inputs. In order to check that the profit function satisfies the basic assumptions that $\pi'(w) > 0$ and $\pi''(w) < 0$, the square of irrigation water is included along with interaction terms featuring water and other inputs (the online Appendix provides greater details). The profit function is estimated separately for irrigators in each sector using a fixed-effects approach. This allows us to control some of the possible correlation between irrigators' unobserved heterogeneity and input choices. As a consequence, all farms that are observed only once in the sample are excluded. The marginal contribution of water to profit based on the estimated coefficients is then calculated, for each irrigator and each year in the sample. This approach is thus an inductive method that uses regression techniques with primary data on agricultural inputs and outputs to estimate the economic value of water (Young 2005);

- w, this is the actual (observed) amount of yearly water used by the irrigator;
- $E(A)$, $E(p_w)$, $V(p_w)$ and $M_3(p_w)$ represent irrigators' expectations of water allocations (A) and expectations on the first three moments of the water price distribution, respectively. Since no information on how irrigators' expectations are formed is available and that findings from the literature are mixed, this study estimated the optimality condition under different assumptions on irrigators' expectations and kept the model that provided the best fit. Two different expectations formation were able to be tested: first, the irrigator is assumed to predict perfectly the level of water allocations and prices (*perfect foresight*); and second, irrigators form expectations based on the level of final allocations and water prices in the previous year (*naïve expectations*). As far as prices are concerned, irrigators may put more weight on prices observed in months when larger volumes are traded and hence may form their expectations based on weighted prices instead.
- Hence, four models are estimated corresponding to the following hypotheses on irrigators' expectations: (i) in Model 1 perfect foresight is assumed for both water allocations and prices and the three moments of the water price distribution will be calculated without using any weights based on traded volume; (ii) in Model 2 naïve expectations and nonweighted prices are used; (iii) in Model 3 perfect foresight and weighted prices are assumed; and (iv) in Model 4 naïve expectations and weighted prices are used.

4.3 Estimation results

4.3.1 Horticulture

The profit function for farms in the horticulture sector was estimated using 1014 observations from 315 farms.[3] The Within R-square is 0.31. Evidence of

[3] Results are shown in online Appendix.

a concave relationship is found between irrigation water and profit, which indicates that the marginal contribution of water to profit is decreasing when the quantity of irrigation water increases. The marginal contribution of water to profit for each farm and each year is calculated using the estimated coefficients. There are some unexpected negative marginal values for 35 observations (around 3% of the sample). In order to exclude outliers from the sample, the distribution was trimmed below the 5th percentile. The final sample of horticultural farms contains 963 observations with a marginal contribution to profit estimated at $547 for an extra ML of water (median is $575), varying from a low of $198 to a high of $623/ML. This range aligns with the results obtained by Wheeler *et al.* (2014b). Figure 2 shows the distribution of the estimated marginal contribution of water to profit. The estimated marginal contribution was found to be similar across years and regions. The main source of variation is the quantity of water used on the farm: the marginal contribution of water to profit decreases with the volume of water used (Figure 3).

The estimated marginal contribution to profit is then used in the second stage to estimate the optimality condition (Eqn 4) under four different sets of irrigator expectation assumptions (Table 2). The only unknown parameters are *REDQ* and *MSQ*. In Models 2 and 4 it is assumed that irrigators have naïve expectations, so these models can be estimated only on the sample of irrigators for which we observe the quantity of water allocations received in the previous year (657 observations overall). In order to permit comparisons across the four models, all four models are therefore estimated using the

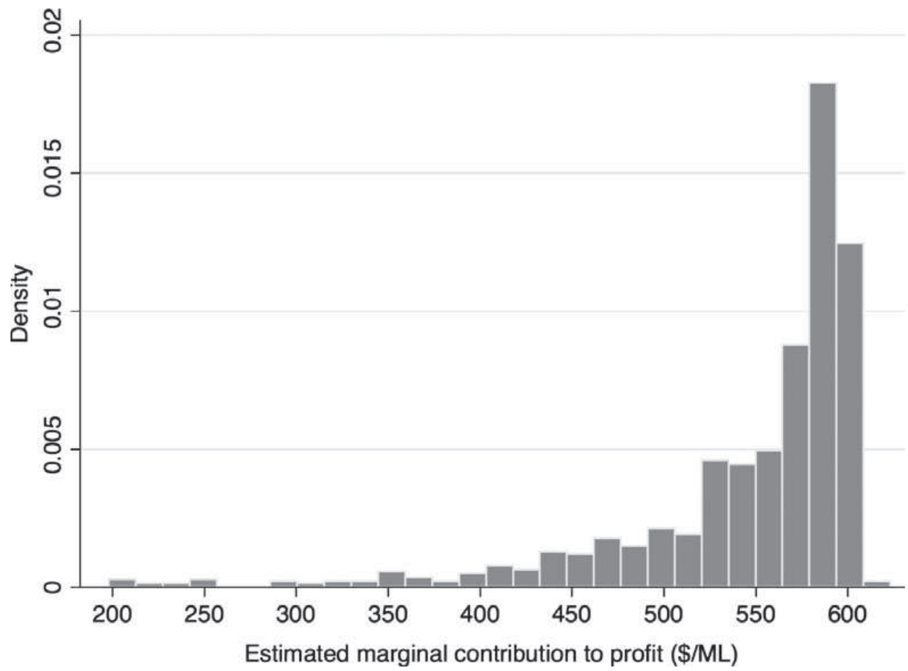

Figure 2 Distribution of the estimated marginal contribution of irrigation water to profit in the horticulture sector (963 observations).

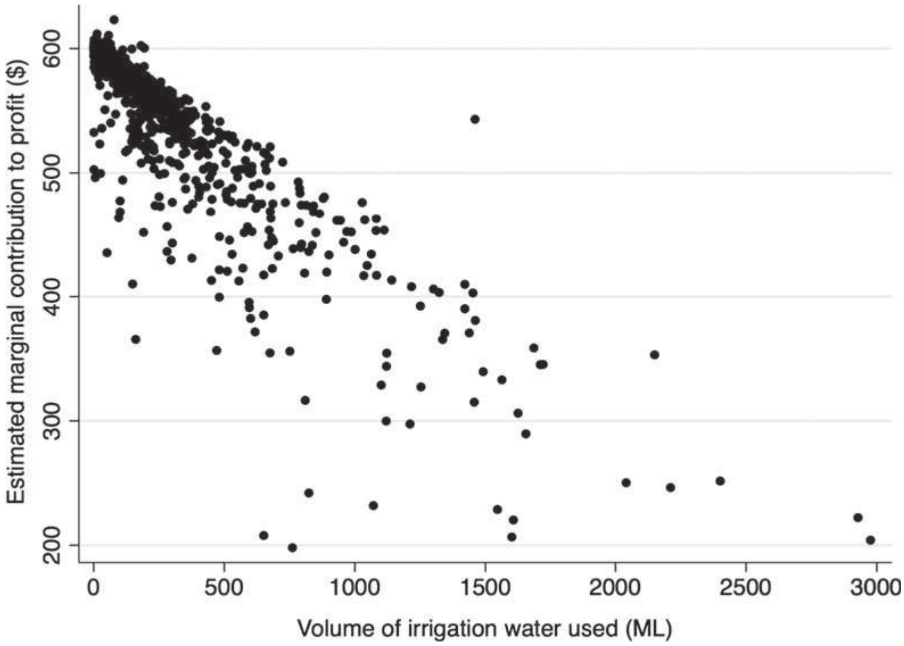

Figure 3 Estimated marginal contribution of water to profit for different quantities of irrigation water used on the farm (horticulture sector, 963 observations).

subsample of 657 observations. Because the estimated models do not include a constant term, R-square cannot be used to assess the goodness of fit so the four models are compared based on their root-mean-squared error (RMSE). The model with the lowest RMSE (and hence the best fit to the data) is the model estimated under the assumption that irrigators form naïve expectations and make their decisions based on (nonweighted) water prices (Table 2).

Model 2 is thus chosen to elicit irrigators' risk preferences and is estimated by nonlinear least squares: *REDQ* is found not significant at usual levels of significance and *MSQ* is negative and significant at the one per cent level of significance (coefficient is −0.0000323). Therefore, the findings suggest that horticultural irrigators display aversion to downside risk (only) since their utility is not affected by the variance of profit. However, they are averse to large profit losses.

4.3.2 Broadacre

The profit function, which is estimated using 543 observations from 177 farms over the 6-year period, displays a within R-square of 0.41.[4] Irrigation water had a positive and significant effect on profit, and the marginal profit increased when larger quantities of irrigation water were used. This is in contrast with what was found in horticulture but may be explained by the fact that water is used in much lower quantities in broadacre in terms of ML/ha of total land (broadacre farms have large dryland areas in addition to large

[4] Results are shown in online Appendix.

Table 2 RMSE for the four irrigators' expectations formation models by sector

	Model 1	Model 2	Model 3	Model 4
Assumptions	Perfect foresight for allocations and price	Naïve expectations for allocations and prices	Perfect foresight for allocations and price	Naïve expectations for allocations and prices
Weighted/ nonweighted prices	Non weighted	Non weighted	Weighted	Weighted
		Horticulture (n = 657)		
RMSE	351.39	276.91	363.57	300.05
BIC	9,578	9,265	9,623	9,370
REDQ	−3.55e-07	−5.65e-07	−1.19e-06**	−1.11e-06**
MSQ	−8.40e-06	−3.23e-04***	−5.55e-04***	−2.82e-04***
		Broadacre (n = 324)		
RMSE	261.21	315.21	272.35	323.11
BIC	4,535	4,657	4,562	4,673
REDQ	−7.23e-07*	−1.12e-07	−6.64e-07	−1.71e-07
MSQ	−2.38e-07	−5.17e-06	−8.18e-08	−4.77e-06

Notes: RMSE, root-mean-squared error; BIC, Bayesian Information criterion; REDQ, Risk Evaluation Differential Quotient; MSQ, Marginal Skewness Quotient.
Significance level: ***$P < 0.01$; **$P < 0.05$; *$P < 0.1$.

irrigated areas) and thus water is less of an essential input than for horticulture.

The distribution of marginal contributions to profit below the 5th percentile also had to be trimmed (estimated contributions were found negative for six observations). On the trimmed sample of 515 broadacre observations, the marginal contribution of water to profit was estimated at

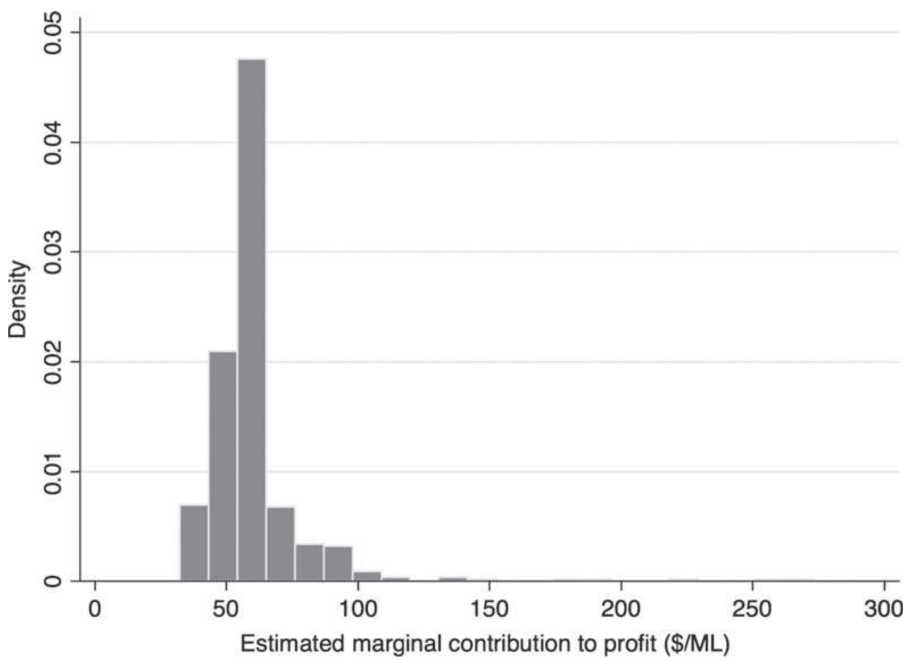

Figure 4 Estimated marginal contribution of water to profit for different quantities of irrigation water used on the farm (broadacre sector, 515 observations).

$61/ML on average, varying from $32 to $273/ML (Figure 4). In the total sample, irrigated area represented 63% of the total operated area in horticulture but only 16% in broadacre. Since the marginal contribution is measured for the profit as a whole (including profit from nonirrigated agriculture), our findings that the marginal contribution to profit in broadacre is about 10 times smaller than the marginal contribution to profit in horticulture are not that surprising.

The comparison of the RMSE for the four models estimated under various assumptions of irrigators' expectations formation shows that the model with current (nonweighted) water prices and levels of allocations (perfect foresight assumption) provides the best fit to the data (Model 1 in Table 2). One possible explanation for this finding (which is in contrast with what was found in horticulture) is that broadacre irrigators who own mainly general security entitlements have much more incentive to forecast and predict their seasonal use of irrigation water. For example, MDB rice growers need to make planting decisions from July to October. If seasonal water allocations are not known, then a variety of factors must be considered. Qualitative findings in Douglas *et al.* (2015) indicated the following influences are considered by rice irrigators when making their planting decisions: opening allocations, water levels in the Blowering and Burrinjuck dams in late winter (August/September), current catchment conditions (whether is it wet or dry), temporary water prices, large-scale climate indicators (El Niño–Southern Oscillation, Southern Oscillation Index) and long-term seasonal rainfall outlook and commodity prices. In addition, rice irrigators in the Murrumbidgee were much more likely to consider a wider range of planting influences than horticultural irrigators in the Riverland. Hence, these qualitative results signal some support for this article's findings.

Model 1's estimation indicates that the *REDQ* was positive and significant at the 10 per cent level of significance (coefficient = 7.23e-07), while the *MSQ* was not found statistically significant. So the findings suggest that broadacre irrigators are risk averse but not averse to downside risk.

Analyses were undertaken for the irrigated dairy sector as well (246 farms and 547 observations). However, the marginal value of water was not found significantly different zero in the first stage model which provided unreliable values for the second stage model. Hence it was not possible to obtain reliable results for the irrigated dairy sector, which confirmed previous hypotheses that the most differences would be found in the horticulture and broadacre sectors.

5. Discussion and conclusion

Although it has been found previously that farmers are risk averse, there have been few empirical studies of the relationship between farmers' risk preferences and their water market trading decisions. Previous studies have made *a priori* assumptions in regard to irrigators' risk preferences. This study sought to avoid making such assumptions and instead sought to elicit risk preferences using farm survey data over a 6-year period (a time period which included seasons of drought and flooding). In particular, irrigators' preferences in regard to variability in profit (*REDQ*) and downside risk (*MSQ*) were investigated for two key sectors: broadacre and horticulture. Dairy was also investigated but no reliable results could be discerned. The results indicated that irrigators in both broadacre and horticulture are averse to risk, which is in line with findings from a majority of empirical studies on farmers' risk preferences, including those conducted in Australia. However, the results also show that horticulture irrigators are primarily averse to downside risk (namely large losses in profit) while broadacre irrigators are averse to the variability in profit. The result that horticultural irrigators are averse to downside risk is not surprising knowing that this industry is based on permanent plantings for which a minimal amount of irrigation water is essential in each season. The risk of financial loss due to water shortage is high, compared to broadacre irrigators who have more flexibility to adjust their planting decision from one season to the other. This finding is consistent with Loch *et al.* (2012) who identified that necessity was a key influence for buying water allocations (particularly for horticultural farmers) in order to keep plantings alive and avoid extreme losses. For selling water allocations, price and income generation were identified as key influences, which enabled broadacre farmers to smooth their income across drought and nondrought years (Loch *et al.* 2012). The high dependence of horticulture on irrigation water is also illustrated in the estimated marginal contribution of irrigation water to profit, estimated at \$547/ML on average over the 6-year period, while the marginal value of irrigation water was estimated at \$61/ML on average in broadacre.

The results also suggest that MDB irrigators may be willing to pay for insurance products that would protect them against the risk of yield or revenue losses. Australian farmers have always been encouraged to develop their own risk management practices, which is especially relevant given that attempts to introduce yield insurance products have failed (Hatt *et al.* 2012). However, even if Australian governments have encouraged farmers' self-reliance and have not been willing to intervene on the insurance market by subsidising insurance premiums, they have traditionally provided drought assistance for 'exceptional' droughts and hence may indirectly compromise the establishment of a competitive insurance market with various products that can pool farmers' risks. Such policies include income support, interest rate subsidies and exit packages. In the Millennium drought of the 2000s, 23% of Australian farms received some drought financial support (Productivity Commission 2009).

Finally, the findings indicate the importance of water markets in transferring water (and risk) across industries and regions in Australia as a risk management tool. However, there is also uncertainty inherent to water markets themselves, since water allocations at the end of the season are unknown and their prices can also vary significantly. So any instrument that would decrease this uncertainty (apart from insurance options discussed above), such as models that would better predict the quantity of water available and hence expected future allocations, greater information provision or the development of secondary markets might be welfare-enhancing for irrigators. Secondary markets for water products could involve agreements to trade entitlements or allocations at a future date, and hence this will include the continual development of contracts such as options and derivatives. The further development of the water market that will increase its use as a key adaptation tool for irrigators is warranted.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Appendix I. Estimation of the profit function.

Table S1. Descriptive statistics for MDB horticultural and broadacre sectors, 2006-07 to 2011-12.

Table S2. Profit function estimates from fixed-effects regressions for MDB horticultural and broadacre sectors, 2006-07 to 2011-12.