2015

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Working Paper: M15_1

RSMG Working Paper Series

Schools of Economics and Political Science

The University of Queensland

St Lucia

Brisbane

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Web: www.uq.edu.au

Elicitation of Murray-Darling Basin irrigators' risk preferences from observed behaviour

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Abstract

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 a perfect case study to elicit the marginal value of irrigation water and irrigators' risk preferences in two key industries with differing levels of dependence on irrigation water. Our data comes from large-scale and representative surveys of irrigated broadacre and horticultural farms in the Murray-Darling Basin over a six-year period. The marginal contribution of irrigation water to profit is estimated at $547 and $61 per mega-litre on average in the horticulture and broadacre sectors, respectively. Irrigators are found to be averse to the risk of large losses (downside risk) in the horticulture sector while irrigators in the broadacre sector 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 regards to their ranking of relative risks (Nguyen et al. 2007). Weather focuses much more predominantly in their 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 allocations (i.e., temporary water rights) in a water market.

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 still rare, mainly because of the lack of wide-spread water markets across the world, but also because of the lack of public access to water market data. Recent analyses using farm survey data include Cristi (2007) on Chile and Zuo et al. (2015) on Australia. In these two studies, irrigators were assumed to be risk-averse. 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. (2015) did not specify any utility function but made the assumption 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.

This study does not make any a priori assumptions on the form of irrigators' preferences towards risk (in other words whether they are risk-averse or risk-loving) and instead adopts a novel approach to elicit risk preferences using farm-survey data. The theoretical framework presented in Calatrava Leyva and Garrido (2006) is employed. 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 irrigators in 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 year to come. Different expectation models are tested, with the one that provides the best fit to the data chosen.

The analysis is based on data for MDB irrigating farms over the seasons 2006-07 to 2011-12. 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 new measures of the value of irrigation water as well as new evidence on Australian irrigators' risk preferences in irrigation industries. The findings also provide new insights on the way Australian irrigators form expectations on future water allocations and prices. Such an understanding of irrigator risk preference and their risk management adaptation 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

In measuring individual risk preferences, the literature has used a variety of methods. For example, using experimental procedures with hypothetical questions (e.g. using lottery questions or gambling tasks); inference from observation of 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 across different domains). Much of the empirical literature has suggested that farmers are risk-averse in most situations (e.g. Saha et al. 1994; Kim and Chavas 2003; Pope et al. 2011; Reynaud and Couture 2012).

Farming in the Australian context is incredibly 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 yield 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 amongst pastoral farmers in New South Wales. 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 the partial coefficient of risk-aversion decreasing with wealth and increasing with income. Ghadim and Pannell (2003) surveyed Western Australian farmers in the mid-90s and found evidence that the majority were risk-averse. Khuu and Weber (2013) found Western Australian farmers to be moderately strongly risk-averse. This article adds to the literature by assessing the form of irrigators' risk preferences (whether risk-lovers or risk-averse) from the observation of irrigation choices and water trading decisions for a sample of irrigated farms operating in the MDB.

2.2 Farmers' expectations

This study also provides new insights on irrigators' expectations regarding the level of water allocations and water prices. Expectations can be formed in a variety of ways, 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 a time-series model of the corresponding variable); and iv) rational (using anticipated supply/demand market conditions). The literature has not yet reached a consensus on which form of price expectation farmers primarily rely on to make price predictions. Fisher and Tanner (1978) used an experimental economics approach with 55 wheat growers in Australia 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 soybeans 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 soybean market: depending on the study reviewed, soybean 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 farmers' expectations of price in the US pork market and found that a large majority of farmers (73%) use quasi-rational expectations, followed by rational expectations (20%) and then naïve expectations (7%).

3. Theoretical framework

This study adopts the theoretical framework described in Calatrava Leyva and Garrido (2006), by considering the case of an irrigator who uses irrigation water as an input, who owns some water rights and has the possibility 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 quantity of irrigation water used in the production process. 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 assumed to be traded at a price p_w. The profit function of the irrigator is thus written as follows:

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

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[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.

where p_q is the output price, *f(.)* the production function and *r* is the vector of input prices. It is assumed that there is uncertainty both in the quantity of water allocations that will be available over the year (*A*) and in the price of water (p_w).

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

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

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

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 the allocations (*A*) and the price of water (p_w), the optimality condition is written:

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

where *V(.)* and *M₃(.)* are the variance and third-order moment of the water price distribution respectively, and *REDQ* (the Risk Evaluation Differential Quotient) and *MSQ* (the Marginal Skewness Quotient) are defined as follows:

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

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 in this equation 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 skewness, 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 mechanics of the model, the relationship between an irrigator's risk preferences and his choice of the optimal quantity of irrigation 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:

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

which is equivalent to:

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

If the irrigator is using more irrigation 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 the variance of the water price is always positive). If the irrigator is risk-averse, we have *REDQ*>0 and hence the numerator in (6) $\left[\pi'(w) - E(p_w)\right]$ has to be positive. The profit function is commonly assumed twice differentiable, with $\pi'(w) > 0$ and $\pi''(w) < 0$, i.e., 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 irrigation water chosen by the irrigator under uncertainty is lower than the level of irrigation water chosen under certainty. So in this case (buyer position), uncertainty (and risk aversion) lead the irrigator to use less water than he would use under certainty.

Conversely, if the irrigator is taking the decision to use less irrigation 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) $\pi'(w) - E(p_w)$ has to be negative. From the properties of the profit function, $\pi'(w) < E(p_w)$ implies that the quantity of irrigation 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 he would use 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 who have been trading on the market. In the following we propose to estimate condition (4) using panel data for a sample of MDB irrigated farms.

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 2006-07 to 2011-12. 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 the production of 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. 2015). Wheeler et al. (2014a) estimated that up to 86% of New South Wales irrigators, 77% of Victorian irrigators and 63% of South Australian irrigators had engaged in at least one water trade by 2010-11. 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 to 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 2006-07 to 2011-12. Considerable variations in water prices and allocation levels were observed during this period. Particularly for water allocations, the monthly mean price almost reached $1000/ML during the 2007-08 season when drought was most severe and fell to as low as $10/ML after flooding in the 2010-11 season.

Figure 1

The ABARES irrigation surveys are conducted via face-to-face interviews and information collected include farm physical and financial variables, input and output variables, water entitlement and allocation trading variables. The irrigation survey is designed as a rotating (unbalanced) panel, with some farms randomly dropped out of the sample after three years. Each farm is classified into one industry based on its' largest receipts; hence one farm 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 unit of water in their production systems. The demand for water in horticultural production is generally more inelastic relative to broadacre production such as pasture and rice (Hughes 2011). This result reflects the fact that broadacre producers' use of irrigation water is more flexible (for example, 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 horticultural crops and lowest for broadacre crops (i.e. pasture, rice and cotton), which is another reason why this study chose horticulture and broadacre as key industries to investigate further.

Table 1 presents the summary statistics for the key variables from the survey data. On average, horticultural farms in the MDB have a much smaller irrigated area than broadacre farms and thus also use less irrigation water. Horticultural farms have a higher farm cash income on average than broadacre farms. Overall, horticultural irrigators are more likely to be a water allocation buyer while less likely to be a seller, particularly during the first four years of the irrigation surveys when the MDB was in drought. After the drought ended, the proportion of horticultural irrigators buying water, and broadacre irrigators selling water, decreased significantly.

Table 1

4.2 Estimation methodology

This study's purpose is to identify irrigators' risk preferences through the estimation of the *REDQ* and *MSQ* terms in Equation (4), as reproduced below:

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

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 water price. We discuss each of the terms in the above equation in turn:

- $\pi'(w)$, the marginal contribution of water to profit, will be calculated from the estimation of a profit function. Profit (or farm net cash income) is specified as a function of the quantity of irrigation 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 irrigation water and other inputs (for greater details on the specification of the profit function, see Appendix I). The profit function is estimated separately for irrigators in the horticulture sector and the broadacre sector using a fixed-effects approach. This allows for some of the possible correlation between irrigators' unobserved heterogeneity and input choices to be controlled. As a consequence, all farms that are observed only once in the sample are excluded. The marginal contribution of irrigation water to profit based on the estimated coefficients is then calculated, for each irrigator and each year in the sample. This approach belongs to one of the inductive methods 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 irrigation water used by the irrigator in the year;
- $E(A)$, $E(p_w)$, $V(p_w)$ and $M_3(p_w)$ represent irrigators' expectations in terms 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 proposes to estimate the optimality condition under different assumptions on irrigators' expectations and to keep the model that provides the best fit to the data. Two different forms of expectations formation

are tested: first, the irrigator is assumed to predict perfectly the level of water allocations and water price (*perfect foresight*); second, it is considered that irrigators form expectations based on the level of final allocations and water price 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. In summary, 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 water 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 non-weighted prices are used; iii) in Model 3 perfect foresight and weighted prices is assumed; and iv) Model 4 uses naïve expectations and weighted prices.

4.3 Estimation results

4.3.1 Horticulture sector

The profit function for farms in the horticulture sector is estimated using 1014 observations from 315 farms.[2] The Within R-square is 0.31. Evidence of 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

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[2] Estimation results are shown in Appendix I.

observations with a marginal contribution to profit estimated at $547 on average for an extra mega-litre (ML) of irrigation water (median is $575), varying from a low of $198 to a high of $623 per ML. This range aligns with the results obtained by Wheeler et al. (2014b). The distribution of the estimated marginal contribution of irrigation water to profit is shown in Figure 2. The estimated marginal contribution of irrigation water to profit is found to be similar across years and regions. The main source of variation is the quantity of irrigation water used on the farm: the marginal contribution of water to profit decreases with the volume of irrigation water used (Figure 3).

Figure 2 and Figure 3

The estimated marginal contribution to profit is then used in the second stage to estimate the optimality condition (Equation (4)) under four different sets of assumptions on irrigators' expectations (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 sub-sample 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 farmers form naïve expectations and take their decisions based on (non-weighted) water prices (Table 2).

Table 2

Model 2 is thus chosen to elicit irrigators' risk preferences and is estimated by non-linear least squares: *REDQ* is found not significant at usual levels of significance and *MSQ* is found to be negative and significant at the one percent level of significance (coefficient is -0.0000323). So our findings suggest that irrigators in the horticulture industry display aversion to downside risk (only) since their utility is not affected by the variance of profit. However they are found to be averse to large losses in profit.

4.3.2 Broadacre sector

The profit function, which is estimated using 543 observations from 177 farms over the six-year period, displays a within R-square of 0.41.[3] Irrigation water is found to have a positive and significant effect on profit, and that the marginal profit increases when larger quantities of irrigation water are used on the farm. This is in contrast with what was found in the horticulture sector but may be explained by the fact that water is used in much lower quantities in the broadacre sector in terms of ML per hectare of total land (broadacre farms have large dryland areas in addition to large irrigated areas) and is less of an essential input than for the horticulture sector.

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 irrigation water to profit is estimated at $61 per ML on average, varying from $32 to $273 (see Figure 4 for the actual distribution). In the total sample, irrigated area represents 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 made from non-irrigated agriculture),

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[3] Estimation results are shown in Appendix I.

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 really surprising.

Figure 4

The comparison of the RMSE for the four models estimated under various assumptions of irrigators' expectations formation shows that the model with current (non-weighted) water prices and levels of allocations (perfect foresight assumption) provides the best fit to the data (Table 3). One possible explanation for this finding (which is in contrast with what was found in the horticulture sector) is that irrigators in the broadacre sector who own mainly general security entitlements have much more incentive to forecast and predict their use of irrigation water during the growing season. For example, rice growers in the MDB need to make planting decisions from July to October. If seasonal water allocations are not known, then a variety of factors must be taken into account. 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 Burrunjick dams in late winter (August/September), current catchment conditions (whether is it wet or dry), the price of temporary water, large-scale climate indicators (El Niño–Southern Oscillation, Southern Oscillation Index) and long-term seasonal rainfall outlook and commodity prices. 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.

Table 3

Model 1's estimation indicates that the *REDQ* is positive and significant at the 10 percent level of significance (coefficient is 7.23e-07), while the *MSQ* is not found statistically different from zero at usual levels of significance. So the findings suggest that irrigators in the broadacre sector are risk-averse but not averse to downside risk.

5. Discussion and conclusion

Although the previous literature indicates that farmers are risk-averse, there have been very few empirical studies of the relationship between farmers' risk preferences and their trading decisions on water markets using real data. Previous literature has made a priori assumptions in regards to irrigators' risk preferences. This study sought to avoid making such assumptions and instead adopted a novel approach to elicit risk preferences using farm-survey data over a six-year period (a time-period which included seasons of drought and flooding). In particular, irrigators' preferences in regards to variability in profit (*REDQ*) and downside risk (*MSQ*) were investigated for two key sectors: broadacre and horticulture. The results indicated that irrigators in both sectors 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. The high dependence of the horticultural sector on irrigation water is also illustrated in the estimated marginal contribution of irrigation water to profit, estimated at $547 per ML on average over the six-year period, while the marginal value of irrigation water was estimated at $61 per ML in broadacre.

The results also suggest that irrigators in the MDB 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 the 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 may include contracts such as options and derivatives. The further development of the water market to be used as an adaptation tool for irrigators is warranted.

Acknowledgements

The assistance of Richard Green, Tim Goesch and Peter Gooday from ABARES is acknowledged in providing data and support. This research was funded by an ARC Discovery project DP140103946.

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Tables

Table 1 Descriptive statistics

	Horticulture			Broadacre		
	Obs.	Mean	Standard deviation	Obs.	Mean	Standard deviation
Irrigated area (ha)	1348	79.2	197.1	758	181.3	441.3
Farm net cash income ($)	1348	117 970	683 742	758	98 623	339 697
Water use (ML)	1348	454.3	1146.3	758	655.5	1642.1
Water allocation buyer (%)	1348	38	49	758	17	38
2006-07	312	30	46	128	27	44
2007-08	310	64	48	129	13	34
2008-09	208	58	49	127	13	34
2009-10	176	41	49	138	17	38
2010-11	178	9	29	117	12	33
2011-12	164	9	29	119	22	41
Water allocation seller (%)	1348	16	37	758	28	45
2006-07	312	25	44	128	16	37
2007-08	310	15	35	129	43	50
2008-09	208	16	37	127	55	50
2009-10	176	13	34	138	33	47
2010-11	178	10	29	117	9	28
2011-12	164	12	32	119	11	31

Table 2 Root Mean Square Error (RMSE) for the four models estimated under different assumptions of irrigators' expectations formation (horticulture, n=657)

Model	Assumptions	Weighted/non-weighted prices	RMSE
Model 1	Perfect foresight for both allocations and price	Non-weighted	351.39
Model 2	Naïve expectations for both allocations and prices	Non-weighted	276.91
Model 3	Perfect foresight for both allocations and price	Weighted	363.57
Model 4	Naïve expectations for both allocations and prices	Weighted	300.05

Table 3 RMSE for the four models estimated under different assumptions of irrigators' expectations formation (broadacre, n=324)

Model	Assumptions	Weighted/non-weighted prices	RMSE
Model 1	Perfect foresight for both allocations and price	Non-weighted	261.21
Model 2	Naïve expectations for both allocations and prices	Non-weighted	315.21
Model 3	Perfect foresight for both allocations and price	Weighted	272.35
Model 4	Naïve expectations for both allocations and prices	Weighted	323.11

Figures

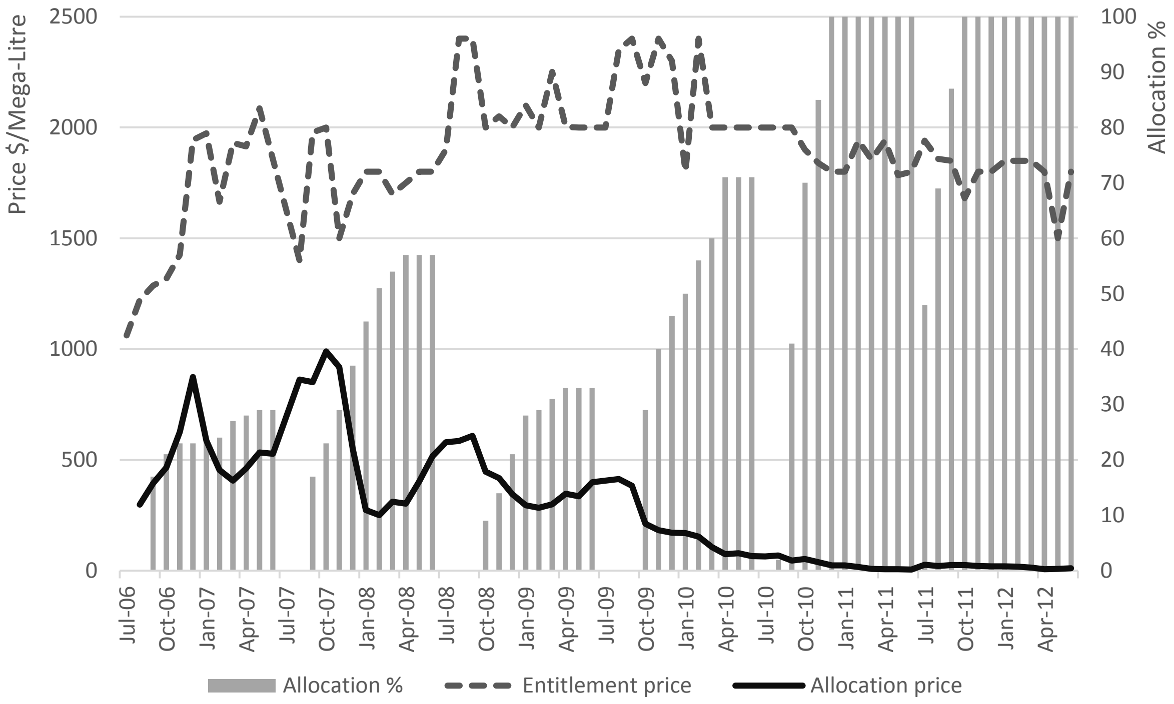

Figure 1 Monthly water allocation/entitlement prices ($/ML) and allocation levels (per cent) in the Goulburn-Murray Irrigation District from 2006-07 to 2011-12

Source: Watermove for 2006-07 and Victoria Water Register for 2007-08 to 2011-12

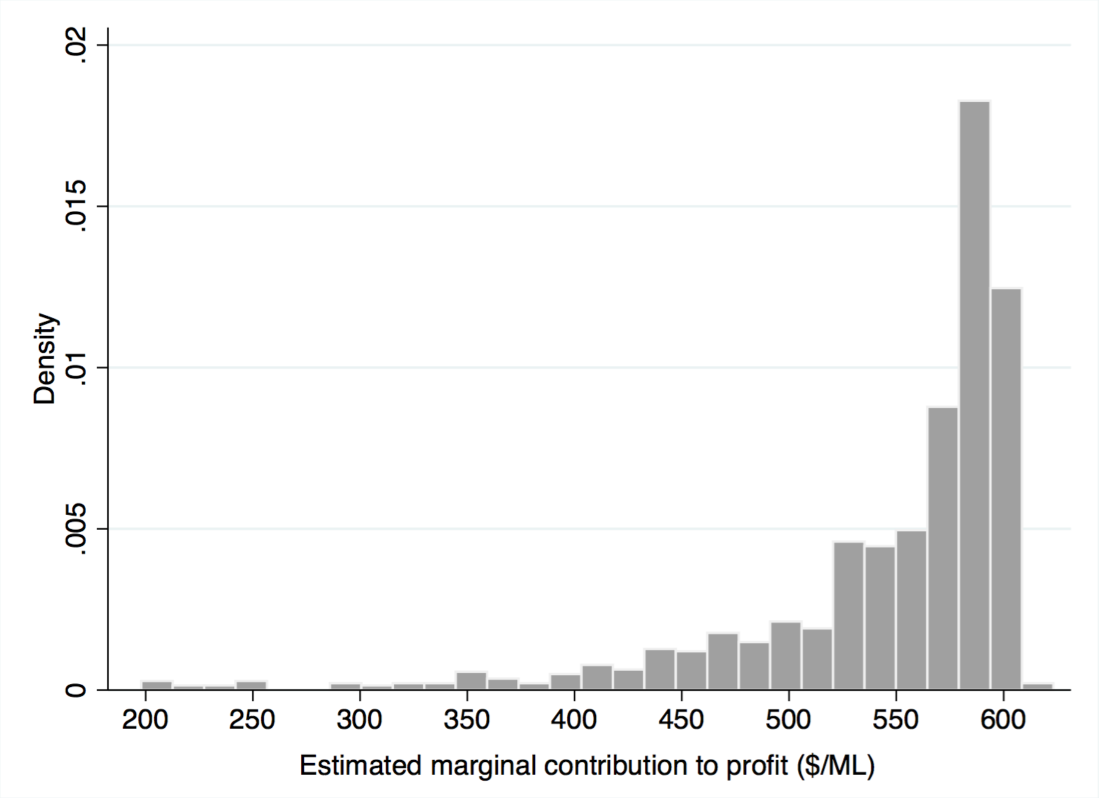

Figure 2 Distribution of the estimated marginal contribution of irrigation water to profit in the horticulture sector (963 observations)

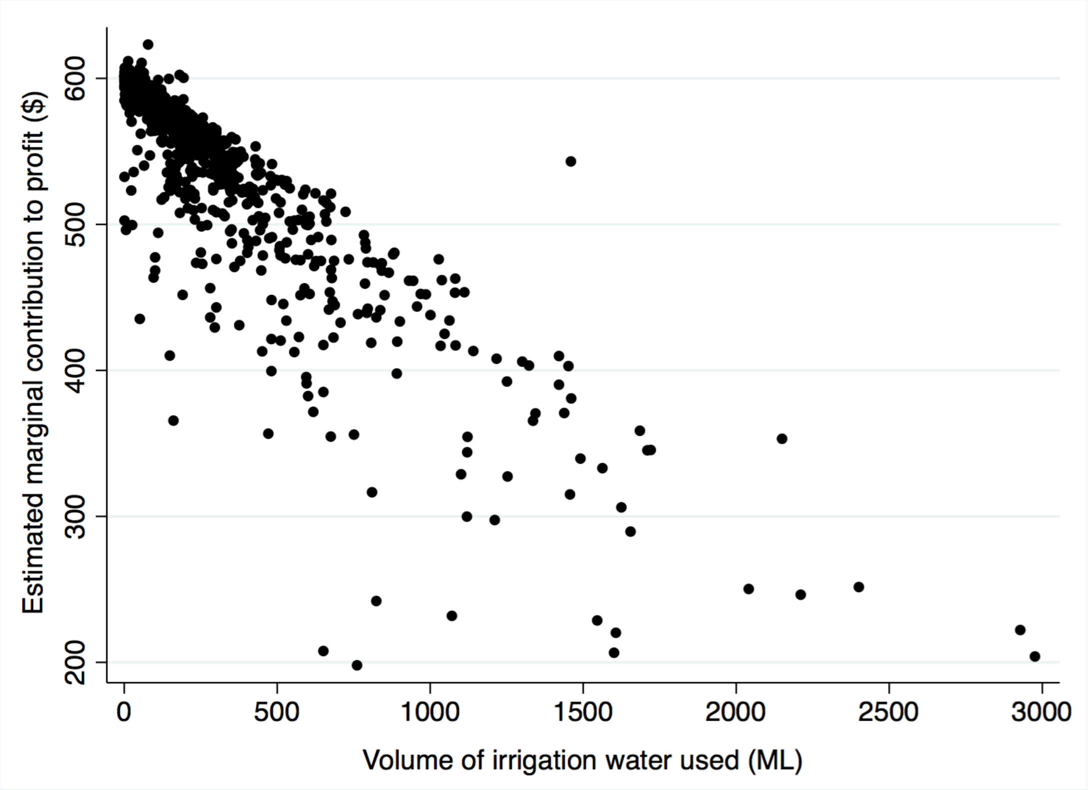

Figure 3 Estimated marginal contribution of water to profit for different quantities of irrigation water used on the farm (horticulture sector, 963 observations)

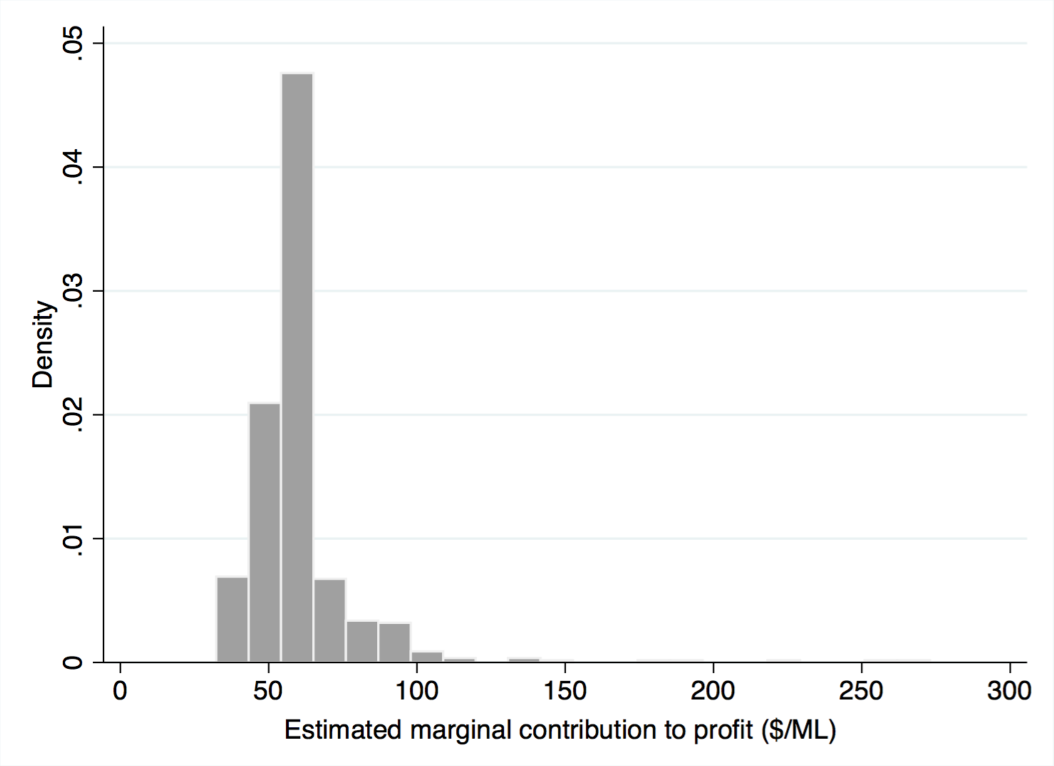

Figure 4 Estimated marginal contribution of water to profit for different quantities of irrigation water used on the farm (broadacre sector, 515 observations)

Appendix I. Estimation of the profit function

The specification of the profit function estimated for farms in both sectors is described below.

Horticulture

The right-hand side variables of the profit equation are the following: fertilisers (quantity index), labour (number of weeks worked), chemicals (quantity index), land area, farm capital, percentage of operated land that is irrigated, irrigation water, irrigation water squared, and cross-terms between irrigation water on the one hand, and fertilisers, labour, and chemicals on the other hand, and year dummies.

Broadacre

The right-hand side variables of the profit equation are the following: fertilisers (quantity index), labour (number of weeks worked), seed (quantity index), chemicals (quantity index), land area, farm capital, percentage of operated land that is irrigated, irrigation water, irrigation water squared, and cross-terms between irrigation water on the one hand, and fertilisers, labour, and chemicals on the other hand, and year dummies.

Table A1 provides the descriptive statistics for the variables used and Table A2 provides the results of the profit functions for the two industries.

Table A1 Descriptive statistics for MDB horticultural and broadacre sectors, 2006-07 to 2011-12

	Horticulture (n=1014)				Broadacre (n=543)			
Variable	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Farm net cash income ($)	146 354	743 427	-2 019 832	14 700 000	102 299	351 138	-855 202	5 293 032
Fertiliser inputs (quantity index)	49 135	148 648	0	1 740 488	60 270	98 452	0	1 360 180
Labour inputs (no. of weeks)	287	510	0	5450	122	106	10	1380
Water-use (ML)	469	1093	0	9282	562	1463	0	17 882
Seed inputs (quantity index)	n.a.	n.a.	n.a.	n.a.	8090	18 892	0	283 302
Chemical inputs (quantity index)	39 948	81 865	0	917 935	41 365	71 264	0	606 200
Total land input (ha)	295	988	2	11 371	2100	4966	18	46 386
Farm capital ($1 000 000)	4	6	0.1	66.3	5	8	0.7	128.4
Irrigated area (% of total land)	62	31	0	100	14	21	0	100

Note: n.a. is for not applicable.

Table A2 Profit function estimates from fixed-effects regressions for MDB horticultural and broadacre sectors, 2006-07 to 2011-12

	Horticulture		Broadacre	
	Coef.	Std. Err.	Coef.	Std. Err.
Fertiliser	2.7***	0.5	0.6	0.4
Labour	401.1***	91.3	-1876.9***	677.7
Water-use	600.1***	101.9	60.8*	35.9
Seed inputs	n.a.	n.a.	3.6***	1.1
Chemical inputs	0.8	0.5	0.2	0.5
Land	-793.8***	153.9	-13.3	15.6
Farm capital	-51 107.0***	9741.7	8361.7	14 301.9
Irrigated area %	-3432.1**	1394.1	997.2	786.2
Interaction: water x fertiliser	-0.0004***	0.0001	-0.0002	0.0002
Interaction: water x labour	0.04	0.05	-0.02	0.16
Interaction : water x chemical	-0.0007***	0.0002	0.00005	0.0002
Interaction: water x water	-0.06***	0.02	0.01*	0.01
2007-08	-15 359.8	40 884.7	43 685.6	37 387.1
2008-09	-3519.3	46 853.6	14 305.3	41 287.0
2009-10	-83 386.0*	50 145.3	-13 176.7	42 289.5
2010-11	38 706.8	53 310.3	28 843.3	44 233.8
2011-12	-63 053.8	57 601.1	20 738.0	49 159.7
No. farms	315		177	
No. observations	1014		543	
R^2 (within)	0.31		0.41	
F-stat	19.4		14.1	

Note: n.a. is for not applicable. Significance levels: *** p<0.01; **p<0.05; *p<0.1