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## TITLE:

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**Water trading as a risk-management tool for farmers:  
new empirical evidence from the Australian water market**

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## **Abstract**

Farmers are well known to be risk-averse. Although a considerable literature has focused on the role water markets play to allocate water more efficiently, none has explicitly studied the risk management role water markets play in irrigators' decision making. We used a two-step empirical procedure to estimate the impacts of variability in profit and downside risk in profit on the volume of water allocation purchased and sold using an unbalanced panel data sample of 1,449 farm observations across four industries in the southern Murray-Darling Basin in Australia from 2006-07 to 2009-10. We show that farmers experiencing higher variability in profit and facing more downside risk purchase greater volumes of water allocations, and this is supported across all irrigated industry sectors (namely, dairy, broadacre, horticulture, and viticulture). There was only weak evidence found for the broadacre industry to suggest that higher variance in profit and greater downside risk drive greater volume of water allocations sold. The different findings between buying and selling water allocations are reflective of the fact that water allocation sellers represent a more heterogeneous group of farmers than water allocation buyers, and that sellers of water allocations may be more strategic in general with their farm management overall.

## 1. Introduction

Water markets have long been advocated by economists as one of the best instruments to enhance efficiency in water use [e.g., *Howe et al.*, 1986]. Some countries have developed water trading schemes, among which the United States (mostly in the western states), Chile (Limarí River Valley), and Australia (Murray-Darling basin) are the most active in terms of the volume traded as a proportion of total water rights available [*Grafton et al.*, 2011a]. By permitting reallocation of water from low-value uses to high-value uses, water markets have proven to be welfare enhancing in a number of cases (e.g., *Vaux and Howitt*, 1984, on California; *Garrido*, 1998, on Spain; *Hadjigeorgalis and Lillywhite*, 2004, on Chile; and *Brooks and Harris*, 2008, on Australia). Another feature of water markets, which will be the focus of this article, is the increased flexibility offered to irrigators to manage the risk of uncertain water availability. Interest in the potential use of water markets as a risk management tool is motivated by the empirical evidence that most farmers are risk averse [*Antle*, 1987; *Saha et al.*, 1994; *Pope et al.*, 2011].

As far as we know, *Calatrava and Garrido* [2005a and 2005b] were the first authors to explicitly address the potential of water markets in terms of farmers' risk reduction in their modeling framework, although *Beare, Bell and Fisher* [1998] estimated the value of irrigation water in Australia under supply and demand uncertainty using a simulation model. Applying mathematical programming models, *Calatrava and Garrido* [2005a] simulate irrigators' production decisions and water exchanges in a hypothetical market in Southern Spain. They show that the possibility for farmers to participate in a water market reduces the effect of uncertainty on their production decisions. In their companion paper, they find that the mean of profit increases and the standard deviation of profit decreases when water trading is allowed [*Calatrava and Garrido*, 2005b]. *Ranjan and Shogren* [2006] develop a theoretical model of a (non-expected) utility maximizing farmer. They show that the success of water markets may

depend on farmers' time preferences and on their subjective weighting of probabilities. In particular, overestimating the probability of loss implies discounting the future value of water and hence induces earlier sales in the water markets. More recently *Lefebvre et al.* [2011] have used experimental data to assess the risk management properties of a market combining low security and high security water rights, relative to a market with a unique type of water right. They find that a two-level security system, in which holders of high security rights are served first in case of scarcity, does not reduce risk overall, rather it allows more efficient risk sharing: less risk averse farmers support a greater share of water variability, and hence may make decisions that could potentially increase the variability of their profits (but increase their average profits), whereas more risk averse farmers make decisions that contribute to a reduction in the variability of their profits, even if this risk reduction strategy induces lower average profits.

In this article we test the hypothesis that water trading is used by farmers to mitigate the risk of water shortage, using four years of recent panel survey data from the southern Murray-Darling Basin (MDB) in Australia. Our empirical analysis focuses on the trading of water allocations (or *temporary water rights*) only, because the market for water entitlements (or *permanent water rights*) is still relatively thin. Water entitlements are an exclusive access to a share of the water resources within an area. Water allocations are the actual volume (or allocations) of water assigned to the permanent water access entitlement. Allocations vary depending on water availability and expected inflows, and depending on the reliability of the entitlement owned.

We assume that risk can influence trading of water allocations through two channels: first, trade is expected to occur because the relative cost associated with the risk of water shortage (and expected commodity returns) differs among farmers. This is because farmers have different financial positions, and different industries can choose crop mixes that may be

more or less sensitive to variations in water supply. For example, farmers with permanent orchards or dairy herds will likely suffer a much higher relative cost of water shortage than farmers planting annual crops. Moreover, within an industry, there can be considerable variation in crop types (for example, vegetables and permanent orchards in horticulture). Second, trade is expected to be enhanced if farmers have different risk preferences. Farmers that are more risk averse may hedge against the risk of water shortage by purchasing water allocations on the market. On the other hand, farmers who are less risk averse and/or who would face lower relative costs in a water scarce situation, may be willing to sell water allocations.

Risk preferences are most often characterized by risk aversion, which implies that decision makers are adversely affected by a higher variance of returns. The concept of downside risk aversion has been less often discussed in the literature. Intuitively, downside risk aversion means that decision makers are averse to being exposed to unexpectedly low returns [Kim and Chavas, 2003]. Empirical evidence suggests that farmers are risk averse in most situations [Saha et al., 1994; Kim and Chavas, 2003; Pope et al., 2011] while evidence of downside risk aversion is more limited [Antle, 1987]. In this paper, under the assumption of risk aversion and downside risk aversion, we test the hypothesis that farmers exposed to a higher variability and a lower skewness of profit (a decrease in skewness implies an increase in downside risk), are more likely to purchase water allocations to hedge against the risk of water shortage, and are less likely to sell water allocations. These hypotheses are tested using a two-stage approach: we first estimate the first three moments of farmers' profit distribution (mean, variance, and skewness) and we then measure their influence on the volume of water allocations farmers are trading. The same approach was used by Koundouri et al. [2006] to study adoption of irrigation technology by risk averse farmers facing production risk in Greece.

We use farm-level data from the southern MDB, where most of the water transactions in Australia occur [NWC, 2011]. Australia southern MDB has one of the most advanced and mature water markets in the world: over 20% of total water rights available are traded annually [Grafton *et al.*, 2011a]. Hence data from this region provide a unique opportunity to assess the potential of water markets as a risk management tool for irrigators. Our data cover the four years from 2006-07 to 2009-10, which encompassed periods of low and high rainfall. The MDB was subject to a severe drought in the 2000s, with water allocations at their lowest from 2006-07 to 2008-09, increasing again in the 2009-10 season. During this period of reduced allocations and exacerbated risk of water shortage, most of the transactions on the water market were driven by risk considerations [see Loch *et al.*, 2012, for qualitative evidence]. We analyze specific industries (broadacre, dairy, and horticulture) separately, in order to minimize differences among farmers in the relative costs of a drought. Variation in trading decisions (whether or not to trade, how much volume to trade) will thus be primarily driven by heterogeneity in risk preferences.

In the next section we briefly present the background of irrigation and water trading in the MDB, and review the factors influencing water trading. Sections providing a description of the data, methodology and discussion of the results follow. The final section concludes the paper and provides some future research directions.

## **2. Background: irrigation and water trading in the Murray-Darling Basin**

The MDB is located in the southeast of Australia, and includes parts of the states of Queensland, New South Wales, Victoria, South Australia, and all of the Australian Capital Territory (Figure 1). It covers 1,059,000 km<sup>2</sup> (about 14% of Australia's land mass) and has a population of approximately 2 million [MDBA, 2010]. In 2009-10 the MDB accounted for

37% of Australia's irrigating agricultural businesses, 53% of irrigated agricultural land and 54% of irrigation water applied. The primary uses of irrigation water in the MDB are cotton (21% of the total irrigation water used in the MDB in 2009-10), pasture for grazing (20%) and other cereals for grain or seed (13%). The MDB represented 38% of the national gross value of irrigated agricultural production in 2009-10. The most prominent irrigated commodity was fruit, whereas only 2% of the value of cereals (for grain and feed) was due to irrigation [Australian Bureau of Statistics, 2011].

#### INSERT FIGURE 1

The MDB region experienced a period of sustained lower than average rainfall from 2000-01 to 2008-09. In 2006-07, although rainfall improved slightly, storage levels remained very low, reaching only 15% of their full capacity, and water allocations reached their lowest levels in some regions as a consequence (see Table A1 in Appendix A). In 2009-10 the MDB experienced rainfall well above the long term average and storage levels began to recover.

The Australian water market comprises a number of separate markets, generally defined by physical water system boundaries [NWC, 2011]. The southern connected MDB (sMDB) water market (including parts of New South Wales, Victoria, South Australia and all of the Australian Capital Territory) has the largest volume of water allocation and entitlement trade. In the sMDB, trading can occur between buyers and sellers, within a region or in different regions or states, within the constraints of defined trading rules, legislation and water plans [NWC, 2011 and 2012]. Water trading is normally facilitated through private brokers (e.g., Waterfind), electronic water exchanges (e.g., Watermove Pooled Exchange), and tenders (e.g., Commonwealth purchases).

As mentioned previously, irrigators in the MDB can trade two types of water rights: i) *water access entitlements* (also called *permanent rights*), i.e., the ownership of the right to a



perpetual entitlement to exclusive access to a share of water from a specified consumptive pool, as defined in the relevant water plan. Regulated entitlements are split between high, general and low security entitlements; and ii) *water allocations* (or *temporary rights*), i.e., the ownership of the right to a specific volume of water allocated in a given season. Each season, water entitlement holders receive allocations based on the amount of water in storages and expected inflows. Opening water allocations are announced at the start of the water season, and subsequently revisions (incremental increases) are announced every two weeks in the sMDB. The allocations are defined as a percentage of the nominal quantity of water entitlement. In some cases, irrigators are allowed to carryover unused seasonal allocation [see *Loch et al.*, 2012 or *NWC*, 2011 for greater details on carryover rules by region]. Table A1 illustrates how end of season allocation levels differ across securities, regions and years.

Water trading first started in the sMDB in the late 1980s and trading activities have been significantly increasing in the past decade. After more than 20 years of operation, the sMDB water market can be considered mature [*Wheeler et al.*, 2009; *Wheeler et al.*, 2010]. Trading on the water market is now fairly common: over 30% of announced water allocations and 10% of water entitlements are traded in the sMDB in some years (*NWC*, 2011).

A number of articles have studied the decision of Australian farmers to participate in water allocation trading using both qualitative and quantitative approaches [*Bjornlund*, 2002; *Wheeler et al.*, 2009; *Wheeler et al.*, 2010; *Loch et al.*, 2012]. Water scarcity appears to be a major influence on participation in the water market (represented by the percentage of farm businesses buying and selling), which increases significantly in times of drought and associated low water allocations, but then drops away when water allocations become high [*Wheeler et al.*, 2009]. However the volume purchased or sold over time by farms has been rarely studied. This article expands this literature by utilizing a new unbalanced four year panel dataset on water allocations traded volumes.

### 3. Factors influencing water trading

This section draws on existing case studies, qualitative and quantitative analyses of farmers' decisions to trade water, mostly from Australia.

#### 3.1. Industry

All farmers using irrigation water as an input in production within the sMDB face some production risk due to the uncertainty on future water allocations, but the relative cost of a water shortage may depend on the industry and the type of commodities produced. Farmers growing perennial crops may suffer significant losses in case of a water shortage. Permanent trees and vines, which can be seen as a long term capital investment for horticultural farmers, could potentially die if exposed to too much water stress [*Quiggin, 2008; Mallawaarachchi and Foster, 2009; Loch et al., 2012*].

Dairy farmers can adopt different strategies when facing a major water shortage: some farmers may decide to purchase water allocations to irrigate pasture and grow feed, while others may prefer to sell allocations in order to purchase fodder [*Mallawaarachchi and Foster, 2009; Loch et al., 2012*].

Broadacre farmers have more flexibility in general to adapt to water scarcity, since in some cases they can switch from irrigated to dryland (or not put a crop in at all), or from water intensive to less water intensive crops. For example, rice and cotton producers may prefer to sell water allocations and reduce the area under production in dry years, instead of purchasing water [*Loch et al., 2012; NWC, 2011*]. Such decisions do have ramifications for regional agricultural production. For example, drought was the cause of rice mills closing in New South Wales, and the end of the drought led to their reopening [*Wittwer, 2011*]. In order

to account for the different strategies available to farmers when facing a drought, the subsequent econometric analysis is conducted separately on the following three main industries: broadacre, dairy, and horticulture (with viticulture analyzed separately).

### **3.2. Farmers' financial capacity**

Farmers' financial capacity may influence water trading. In what follows we use debt level and farm capital to control for farmers' financial capacity. We expect more indebted farmers (or those with less farm capital value) to be less likely to purchase water allocations, all other things equal. Farmers facing a difficult financial situation may also be more willing to sell water allocations in order to receive additional (certain) income.

### **3.3. Water ownership, allocations and rainfall**

We expect farmers holding larger high security and general security entitlements, and farmers receiving a higher percentage of their water allocations, will be less likely to purchase water allocations but more likely to sell, all other things equal. *Wheeler et al.* [2010], using data on Australian farmers (Goulburn-Murray Irrigated district) from 1998-99 to 2003-06, find evidence that farmers owning greater water entitlements sell more water allocations.

We expect rainfall will have some influence on water trading. Higher rainfall in a given region will decrease the need for additional water and, consequently, decrease the probability of buying and increase the probability of selling. Rainfall will therefore directly influence the demand for water in the market as well as the market price of water allocations.

### **3.4. Prices of water allocations and commodities**

We expect water prices to influence water trading, with possible differences across industries [*Loch et al.*, 2012]. In industries where water stress may be detrimental to long term investments (perennial crops for horticultural farmers, herd for dairy farmers), the demand is

expected to be more price inelastic if purchasing water is the only solution to keep the farm business viable.

The price of water allocations is expected to have a greater influence on broadacre farmers (in particular rice and cotton producers), who often decide to trade on the water market based on the relative prices of water and commodities [NWC, 2011]. Using farm data from Australia over the years 2000-2004, *Bell et al.* [2007] found that water demand in general was more elastic in farms engaged in broadacre and dairy activities than in horticultural farms. The influence of the price of water allocations on sellers is also likely to be one of the main reasons for selling water. A higher water price is expected to drive larger sales for opportunistic or annual crop farmers, while the price of water allocations may not influence the sale decisions of farmers who need their water for farm production, especially permanent crops.

The price of water allocations will likely be considered by farmers in conjunction with commodity output and input prices, i.e. the price at which farmers can expect to sell their production or the price of input substitutes for water. For example, when the water price is above AUD 150–AUD 200 per mega liter (ML), rice growers in New South Wales usually receive a higher return from selling their water allocations than producing, hence are more likely to choose to sell water [NWC, 2012]. On the other hand, dairy growers in Victoria are more likely to choose to sell water allocations, stop watering pasture and buy feed barley for cows if water allocations rise above AUD 300/ML [*Wheeler et al.*, 2008].

### **3.5. Farmers' characteristics**

*Wheeler et al.* [2010] compared the profile of traders in 1998-99 and 2003-06 and found evidence that farmers' characteristics (age, years in farming) have become less important in driving farmers' decision to trade once the market has become more mature. The

only persistent effect seems to be that farmers with low education levels are less likely to trade. In the subsequent empirical application, we will consider the age and education level of the farm's operator.

We also control for heterogeneity across farms by including the size of the farm as an explanatory variable for the volume of water allocations traded. Farmers that own larger farms are often found to be less risk averse than those that own smaller farms. We would therefore expect farmers that own larger farms will purchase smaller volumes of water allocations and sell larger volumes of water allocations. This is a property of risk preferences known as DARA: Decreasing Absolute Risk Aversion [*Chavas and Holt, 1996*].

### **3.6. Uncertainty**

Risk on future water availability translates into uncertainty on future profits. If farmers are risk averse, they will be adversely affected by a higher variance of returns. Consequently they may decide to purchase water allocations on the market in order to hedge against the risk of profit variability [*Loch et al., 2012*]. In addition to the variance of profit (the second order moment), we test for the influence of *skewness* (or the third order moment), which is a measure of the asymmetry of the profit distribution, on farmers' decisions to trade water allocations. A negative value (also known as "skewness to the left", i.e. the tail on the left side of the probability density function is longer than the right-side tail) is associated with "downside" risk (hence a decrease in skewness implies an increase in downside risk). Purchasing water allocations on the market could contribute to mitigate downside risk by reducing the risk of extremely bad outcomes. In the subsequent empirical analysis, and under the assumption that farmers are risk averse and averse to downside risk, we test the hypothesis that farmers experiencing higher variability in profit and farmers facing more downside risk

(i.e. farmers for which the third moment is smaller) are likely to purchase more water allocations, and to sell less water allocations on the market.

#### **4. Description of the data**

This study uses farm-level data on physical and financial variables for agricultural production, obtained from surveys conducted on farm by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES). The ABARES survey of irrigation farms, which covers 10 regions throughout the MDB, has been conducted annually since the 2006-07 financial year. For greater details about the sampling strategy and the survey itself, see *Ashton and Oliver* [2012]. Surveys are conducted on-farm, and obtain as much accounting and farm records as possible. The records contain information on: land area; crop and livestock production and sales; expenditure on fertilizers, chemicals, seed, fodder; labor; profit; capital; debt; types of water licenses held; type and size of water entitlements; and irrigation water use and participation in the water market. More specifically, the volumes of water allocations and entitlements purchased and sold each year by each farmer are recorded in the data.

Expenditures on fertilizers and chemicals were converted into quantity indices using the corresponding price index. Expenditures on seed and fodder were transformed into quantity indices using the consumer price index [source: *ABARES*, 2011]. The data also contain information on the age and education level of the main operator of the farm.

The ABARES survey of irrigation farms targets farmers from three industries: broadacre (including rice and cotton), dairy, and horticulture. About 850 farms are surveyed each year (in a rotating panel). Our subsequent analysis will focus on farms in the sMDB and the three regions of Goulburn, Murrumbidgee and Murray, where close to three quarters of the surveyed farms are located (Figure 1). Four years of irrigation farm data are available so

far (from 2006-07 to 2009-10). These survey data were complemented by information on rainfall obtained from the Australian Water Availability Project and merged with the survey farms data using Geographic Information System software. Monthly farm-specific rainfall data were then used to create two annual variables: winter rainfall and summer rainfall, which are defined as total rainfall from April to October and total rainfall from November to March in each year, respectively.

The data on the mean seasonal price of traded water allocations has been compiled from Waterfind Annual Water Market Reports 2008-09 and 2009-10. The price of water varies across years, regions and states (Table 1). The highest prices were observed in 2007-08 while prices were at their lowest at the end of the period, in 2009-10. In 2006-07, prices varied significantly across regions, from a low of AUD 194/ML in Murrumbidgee to a high of AUD 485/ML in Goulburn.

INSERT TABLE 1

In total, 1,449 observations were available for our analysis over the four years of the survey. By industry, the observations were: broadacre (385), dairy (294), and horticulture (770).

Broadacre farms and horticultural farms are almost equally represented in the Murrumbidgee region (Table 2). Horticultural farms dominate in the Murray region (62% of observations from this region in our sample). The three industries are all represented in Goulburn, with a higher number of observations from dairy farms (47%) and horticultural farms (38%).

INSERT TABLE 2

In our sample, the proportion of the surveyed farmers who purchased water allocations on the market varies from 28% in 2009-10 to 45% in 2007-08 (Table 3). The proportion of farmers selling water allocations is slightly lower, varying from 18% in 2009-10 to 27% in

2008-09. This is partly explained by the relatively low level of water allocations over the period under consideration: the average water allocation by the end of the season was 17% in the broadacre sector, 20% in the dairy sector and 38% in the horticultural sector. This reflects the differing levels of security across regions and states, with New South Wales traditionally owning larger and less secure water entitlements in the form of general security. High security water entitlements are more generally owned in the Goulburn and the Murray (predominantly horticultural and dairy farmers). From 2007-08 to 2009-10 there was a higher number of water allocation sellers among the surveyed farmers from the broadacre industry than buyers. On the other hand, horticultural farms and dairy farms have been mostly buyers on the market, rather than sellers.

#### INSERT TABLE 3

In our sample, the total volume of water allocations purchased was at its highest at the peak of the drought in 2006-07 (28,086 ML). It remained quite high until 2008-09 and decreased to 16,816 ML in 2009-10, when high rainfall occurred over the region. The graph in Figure 2 illustrates that horticultural farms purchased most of the water allocations on the market in 2007-08 and 2008-09, at the time when the price on the market was at its highest (Table 1). Buying water on the market may be the only possibility for horticultural farmers to save their perennial trees in case of water shortage [*Loch et al.*, 2012]. Their plantings are likely to be at higher risk when water allocations are low and, consequently, when the price on the market is high. On the other hand, farmers from the broadacre industry appear to be more responsive to the price of water since they purchased relatively more water allocations from the market when the price was low (in 2006-07 and 2009-10). Dairy farmers are also responsive to prices: the volume of water allocations they purchased was at its lowest in 2007-08, when the price of water peaked.



INSERT FIGURE 2

INSERT FIGURE 3

The volume of water allocations sold is lower than the volume of water allocations purchased: it varies from a total of 10,091 ML in 2009-10 to 15,699 ML in 2008-09. From 2007-08 until 2009-10, most of the water allocations were sold by broadacre farmers, with higher volumes traded when the price of water was at its highest in 2007-08 and 2008-09 (Figure 3). In general dairy farmers have sold low volumes of water allocations. Some horticultural farms sold water allocations on the market, in particular in 2006-07.

For most of the farmers who purchased or sold water allocations, the amount of water traded represents a significant proportion of water they received. Figure 4 shows the percentage of water allocations (in volume) that are purchased and sold by water buyers and sellers, respectively. We report the median percentage from 2006-07 to 2009-10 (the median is used rather than the mean, as the distribution is highly skewed). The volume of water purchased by buyers from the dairy sector represents 84% of their seasonal allocations. This proportion is lower for horticultural farms (73%) and broadacre farms (42%). Dairy farms also have a high percentage (73%) of water allocations that are sold, respective to seasonal water allocations received, while horticultural farms sell the smaller proportion (34%) of their water allocations received.

INSERT FIGURE 4

Some farmers both purchased and sold water allocations in a single year. This is a rare event on our sample though, since it represents 5% of the observations in the broadacre sector, 2% in the dairy sector and 4% in the horticultural sector. Unfortunately we do not know the timing of these sales. However, other qualitative research tells us that such a scenario seems to be driven mostly by risk adverse farmers buying water early in the season before prices

rose, and selling surpluses later in the season once full water allocations were known [Loch et al., 2012].

## 5. Empirical approach and model specification

Our analysis proceeds in two steps: we first estimate the first three central moments of the profit distribution for each farmer in our sample, and second, we estimate the volume of water allocations purchased and sold on the market. We describe the two steps in turn.

### 5.1. First stage: estimation of the moment equations

The moments of the profit distribution are calculated following the sequential procedure described by *Kim and Chavas* [2003] and subsequently used by *Koundouri et al.* [2006]. The underlying idea is to specify a functional form for each moment of the profit distribution.

The central moment of order  $j$  ( $\mu_j$ ) is defined as follows:

$$\mu_j = E \left[ (\pi(\cdot) - \mu_1)^j \right] \quad (1)$$

where  $\mu_1$  is the first central moment and  $\pi(\cdot)$  represents farmer  $i$ 's profit function in year  $t$ , specified as follows:

$$\pi_{it} = \pi(\mathbf{x}_{it}, \mathbf{z}_{it}) + \eta_i + u_{it} \quad (2)$$

Our main purpose is to capture profit variability through the residual ( $u_{it}$ ). Profit variability can be driven by a number of factors, including variability in the commodity and input prices, variability in weather conditions, and variability in the quantity (and quality) of commodities produced. In order to capture variability in profit, we propose to include, as explanatory

variables in the profit equation, those decisions that are under the control of the farmer, i.e. the quantities of inputs used over the entire season (gathered in  $\mathbf{x}$ ). The rest (quantities produced, commodity prices, weather conditions) are not under the farmer's control and contribute to profit variability. We also include the size of the dryland and irrigated land on the farm as the area operated, along with region and year dummies ( $\mathbf{z}$ ) to remove any general trend, either across regions or across years that may have affected all farmers identically. We also control for unobserved farmer-specific effects ( $\eta_i$ ), which are assumed to be random. We assume a quadratic relationship in all inputs and we estimate the model using Generalized Least Squares. Based on (1), the estimated errors  $\widehat{u}_{it}$  in model (2) are estimates of the first central moment of the profit distribution. These estimated errors are then raised to the power two and regressed on the same set of explanatory factors:

$$\widehat{u}_{it}^2 = \widehat{u}_{it}^2(\mathbf{x}_{it}, \mathbf{z}_{it}) + u_{it}' \quad (3)$$

The predicted values in model (3) are consistent estimates of the second central moment of the profit distribution (or variance). The same procedure applies to calculate the third moment (or skewness). We use Ordinary Least Squares to estimate the second and third moment equations, since farmer-specific effects ( $\eta_i$ ) have been wiped out in the calculation of the first-stage residuals.

The three moment equations are estimated separately on the three main industries: broadacre, dairy, and horticulture (with viticulture separate), to take into account that farmers in different industries may operate under different technologies. The set of inputs (vector  $\mathbf{x}$ ) varies from one industry to the other (see Table A2 in Appendix for a list of the explanatory variables used in the moment equations). Profit (or farm cash income which represents surplus farm income available after paying for cash operating costs) is calculated as the total

revenues on the farm during the financial year less total payments for materials and services, and for permanent and casual hired labor.

## **5.2. Second stage: estimation of the volumes of water traded**

In the second stage, we estimate separate models explaining the volume of water allocations purchased and the volume of water allocations sold in each industry. Because a number of farmers did not trade in each year, we estimate Tobit models using the Maximum Likelihood technique. Monetary values have been converted into AUD 2010 prices using the consumer price index [source: *ABARES*, 2011]. Consistent standard errors are calculated using bootstrapping techniques (using 500 replications). The set of explanatory factors introduced in each model is the following:

- the first three (estimated) central moments of profit;
- commodity prices (for each commodity, the price is calculated as the ratio of sales value to quantity sold. For farmers who do not produce/sell a commodity, the price is the median price in the region in the corresponding year);
- farm size (or area under operation);
- farm capital;
- average regional price of water allocations on the market (AUD/ML);
- high security entitlements owned by the farmer (ML);
- general security entitlements owned by the farmer (ML);
- water allocations received at the end of the season (%);
- debt;
- farmer's age;
- farmer's education level;
- winter rainfall; and

- regional dummies.

Greater details on these variables, including definition, units of measurement and average value for each industry, can be found in Table A3 in Appendix.

The price of water allocations included in our models is the average price at which allocations were traded over the entire season. Prices vary across years and regions (Table 1). Because of the large number of transactions that occur in the market in each season, each farmer is too small individually to influence the average price of traded water allocations. For this reason the average regional price can be assumed exogenous in the models describing the volumes of water traded at the farm level.

A number of other variables were available from the survey, including the amount of water that was carried over from the previous season as well as information on work outside the farm. Because of a large number of missing information and potential endogeneity issues, we decided not to use these variables in the Tobit models. Because the water market has become mature and water trading is, in most cases, part of farmers' production decision making, the decision to work outside the farm might have been taken simultaneously with the decision to trade water. Year dummies were not included in the model to avoid collinearity with the price of water allocations and level of rainfall.

## **6. Estimation results and discussion**

The first stage of our empirical analysis involves the estimation of the first three central moments of the profit distribution. Estimation results are not shown here, but are available from authors upon request. The overall  $R^2$  varies from 0.14 for the profit equation in the horticultural sector to 0.74 in the broadacre sector. The lower fit in the horticultural industry

may be explained by a greater heterogeneity among farmers, since this industry gathers, among others, producers of fruit (pome fruit, stone fruit, or citrus fruit), grapes, and vegetables. In order to control for part of the heterogeneity in this sector, we also estimated the three moment equations on the sub-sample of viticultural farmers (286 observations), which is likely to be a more homogeneous sample than the sample of horticultural farms (the profit equation has a  $R^2$  of 0.31 for the viticultural farms).

In Table 4 we report the average estimated variance and average estimated skewness, separately for the group of buyers (of water allocations) and for the group of sellers in each industry. We also test if the mean in each group is statistically different from the mean calculated on the sub-sample of non-buyers and non-sellers, respectively. For example, the number 10.340\*\*\* indicates that the estimated variance is 10.340 for broadacre farmers who purchased water allocations on the market. This average variance is statistically different (at the one per cent level of significance) from the average variance calculated for broadacre farmers who did not purchase water allocations on the market. These figures illustrate that the (average) variance and skewness of the profit distribution are statistically different for buyers compared with non-buyers, and sellers compared with non-sellers. Consequently, we expect the second and third central moments of the profit distribution to explain part of the volume of water allocations traded in the second stage of the econometric analysis. We also observe that the estimated variance is higher among the group of buyers than among the group of sellers, on average, which seems to confirm our hypothesis that farmers experiencing higher volatility of profit are more likely to buy water allocations. In terms of skewness, the results are not really as expected, except in the case of dairy: if farmers exhibit downside risk aversion, we expect farmers with more negative skewness to be more likely to buy water allocations, and less likely to sell water allocations.

INSERT TABLE 4

In the second stage, we identify factors influencing the volume of water allocations purchased and the volume of water allocations sold. We report the corresponding marginal effects in Tables 5 and 6, respectively. To a large extent the findings confirm our main hypothesis: farmers who experience higher variability in profit (as measured by a higher variance or higher second order moment), and who are more likely to face extremely bad outcomes (as measured by a lower skewness or third order moment), will purchase a larger volume of water allocations and will sell a smaller volume of water allocations, all other things being equal. These effects are stronger in the model explaining the volume of water allocations purchased than in the volume of water allocation sold models. In the models describing the volume of water allocations purchased, the marginal effects of the estimated variance are statistically significant in all the four models (broadacre, dairy, horticulture, and viticulture) and three out of four of the marginal effects of the estimated skewness are statistically significant (Table 5). The third order moment in the broadacre model has the expected negative sign but is not significant at usual levels of significance. One possible explanation is that farmers in the broadacre industry, who mainly grow annual crops, are less likely to suffer extremely bad outcomes than farmers from other (more risky or permanent) industries.

INSERT TABLES 5 AND 6

We do not find such clear-cut influence of risk related variables on the volume of water allocations sold on the market, which may indicate that risk motives are not the main determinants of the volume of water allocations sold on the market. Indeed farmers from the broadacre, dairy, and viticultural sectors facing a higher variability of profit are selling less water allocations or not selling any, but the corresponding marginal effect is significant only for broadacre and viticultural farmers. The third moment of profit (or skewness) has the expected positive sign only in the broadacre sector, but is not significant (Table 6). These

different results between buyers and sellers of water allocations corroborate findings in *Zuo et al.* [2012]. These authors analyzed time series data of water bidding behavior of buyers and sellers of water allocations from 2001 to 2011 in the Goulburn-Murray Irrigation District, and found buyer clustering behavior was mostly explained by risk aversion levels and increased uncertainty in the water market, while seller clustering behavior was mostly explained by strategic behavioral considerations.

Most of the other variables, when significant, confirm our initial expectations: larger farms (as measured by the size of the area operated) in the dairy sector purchase lower volumes of water allocations, and sell larger volumes than their smaller counterparts, all other things equal. We also find that farms with a larger number of cattle are less likely to sell water allocations. The size of the farm has also a significant and negative impact on the volume of water allocations purchased in the viticultural industry, which may be an indication that farmers owning larger farms are less risk averse in general (or, equivalently, exhibit Decreasing Absolute Risk Aversion -type of preferences).

Dairy farmers with a higher level of debt purchase lower volumes of water allocations, confirming that the financial position of a farm has an influence on the decision to purchase water on the market. As might be expected, a higher level of winter rainfall is found to reduce the volume of water allocations purchased by dairy and horticultural farms on the market. However, greater winter rainfall decreases the water allocations sold in the horticultural industry, which was not an expected result.

Our findings confirm that the quantity of water received by the farmer, which is measured through the final percentage of water allocations received and the total level of high security and general security entitlements owned, were found to be important drivers of the volume of water traded, in particular in industries growing permanent crops (horticulture and



viticulture). In the viticultural industry higher levels of both high security and general security entitlements, and greater water allocations received at the end of the season, significantly decrease the volume of water allocations purchased on the market (Table 5) and increase the volume of water allocations sold (Table 6). Greater water allocations also decrease the volume of water purchased and increase the volume of water sold by horticultural farmers. These effects are less significant in general in the broadacre and dairy sectors.

The price of water allocations is not found significant in any of the models describing the volume of water allocations purchased. Interestingly, the sign of the price variable is positive (but not significant) in the horticulture and viticulture sectors, which probably illustrates the need for farmers growing permanent crops to buy water on the market when water is scarce (and price is high). On the other hand, a higher price significantly increases the volume of water allocations sold in the dairy and horticulture industries (the effect is positive also for viticultural growers, though not significant). This confirms findings of *Wheeler et al.* [2008] that a trigger price exists above which dairy farmers decide to buy feed barley (to feed cows) and to stop irrigating pasture (the trigger price was estimated at AUD 300/ML for farmers in Victoria).

Our results also indicate that dairy farmers who have a lower education level (four years of high school completed at the maximum) are less likely to trade higher volumes: this effect is found significant for both purchased and sold models. These findings are in line with those described by *Wheeler et al.* [2009] and *Wheeler et al.* [2010]. In addition, some regional effects were found, with horticultural farmers in the Murrumbidgee region more likely to sell water allocations and less likely to purchase water allocations, which is probably reflective of greater water holdings in New South Wales horticulture than other states.

## 7. Conclusion

While a number of studies have focused on the role water markets play to allocate water more efficiently among irrigators, our research expands this literature by explicitly studying the risk management role water markets play in irrigators' decision making. Given previous findings from the agricultural economics literature, we assume that farmers are in general risk averse and averse to downside risk. We hypothesize that farmers experiencing higher variability in profit and facing more downside risk are likely to purchase a higher volume of water allocations, and to sell a lower volume of water allocations on the market, everything else being equal.

A two-step empirical procedure was carried out to estimate the impacts of variability in profit and downside risk in profit on the volume of allocation water purchased and sold using a sample of 1,449 observations across four industries in the sMDB over four years. Our results overall confirm the hypothesis that farmers experiencing higher variability in profit, and facing more downside risk, purchase more water allocations. This is strongly supported across the dairy, horticulture, and viticulture sectors, and weakly supported in the broadacre sector. However, there is only weak support to suggest that higher variance in profit and greater downside risk drive the volume of water allocations sold, this evidence was only mainly found in the broadacre sector. The different findings between buying and selling water allocations may reflect the fact that sellers represent a more heterogeneous group of farmers than buyers. Buyers mostly are in need of water to grow their crops and mainly consist of permanent industries. Sellers generally come from the broadacre industry where their increased farming flexibility and greater excess water capacity means that they are far more likely to be sellers of water allocations. Evidence also suggests that sellers of water

allocations may be more strategic in general with their overall farm management. Some further research is needed to improve our understanding of sellers' motives.

Future research should also consider the timing of water allocations trading within a season, since the risk irrigators are facing changes when the allocation level is revised throughout the season. Finally further insights would be gained by studying not only trading of water allocations but also trading of permanent water entitlements.

The results of this paper, especially the purchase models, illustrate how effective water markets can be in providing irrigators from the MDB with an instrument to manage the risk of water shortage. Similar results are expected to hold for water markets in other countries, such as the western US and the Chile Limarí Valley. However the effectiveness of water markets as a risk-management tool will also depend on the characteristics and rules of each market. As discussed by *Grafton et al.* [2011a and 2011b], institutional foundations, regulatory capacity, stability of price and availability of price information among other factors differ from one water market to another. In the western states of the US for example local markets are quite thin, causing considerable annual fluctuation in prices across time, jurisdictions and sectors. As a result, it is extremely difficult for irrigators to gauge future water prices and consequently discourage participation in the water market [*Grafton et al.*, 2011b]. Despite the fact that water markets in Australia are usually considered far advanced and well developed, water markets across regions in the sMDB still have many inconsistent rules regarding carry-over, storage, transfers, caps, water allocations announcement and rules governing water organizations [*NWC*, 2011]. The water market is complex, with hundreds of different water products across the Basin, which can prove confusing for irrigators and reduce their ability to estimate the best water market strategy for themselves. The role of water markets as a risk-management tool for farmers in the MDB could thus be further enhanced by continuous improvement in the market institutional infrastructure and functioning rules.

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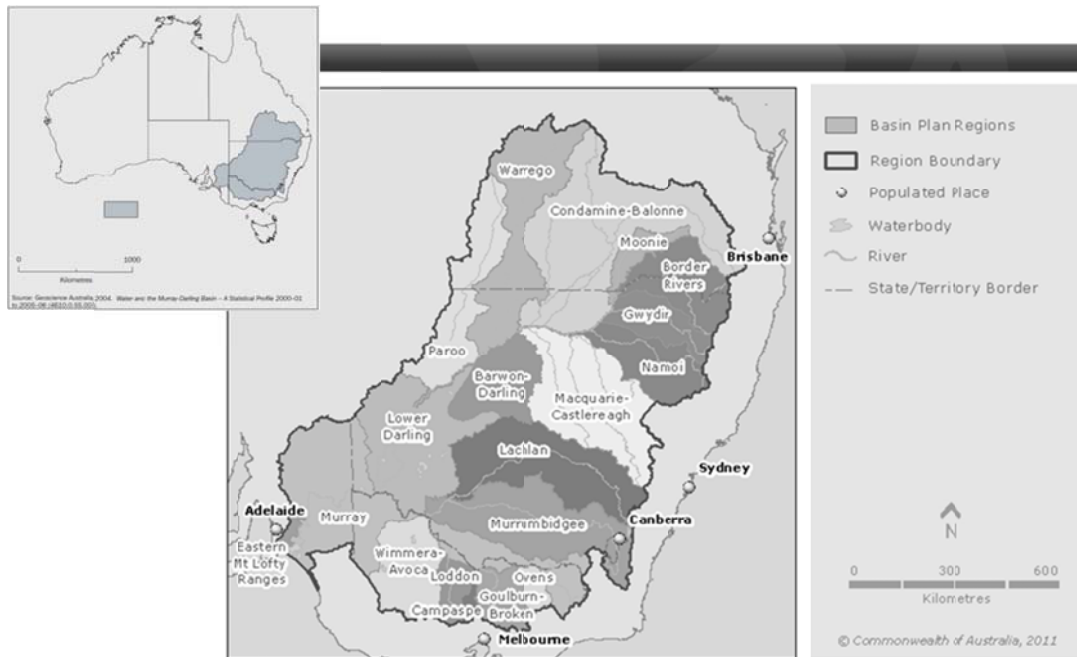
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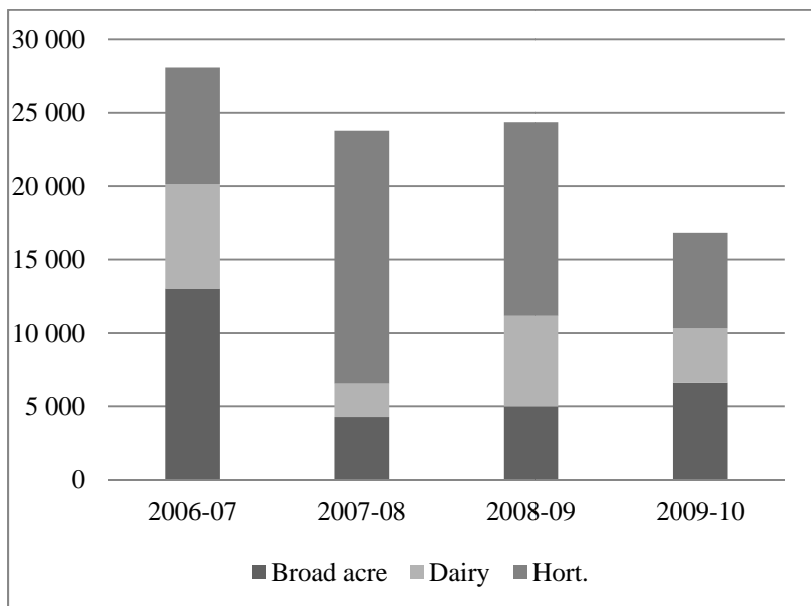
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## Figures

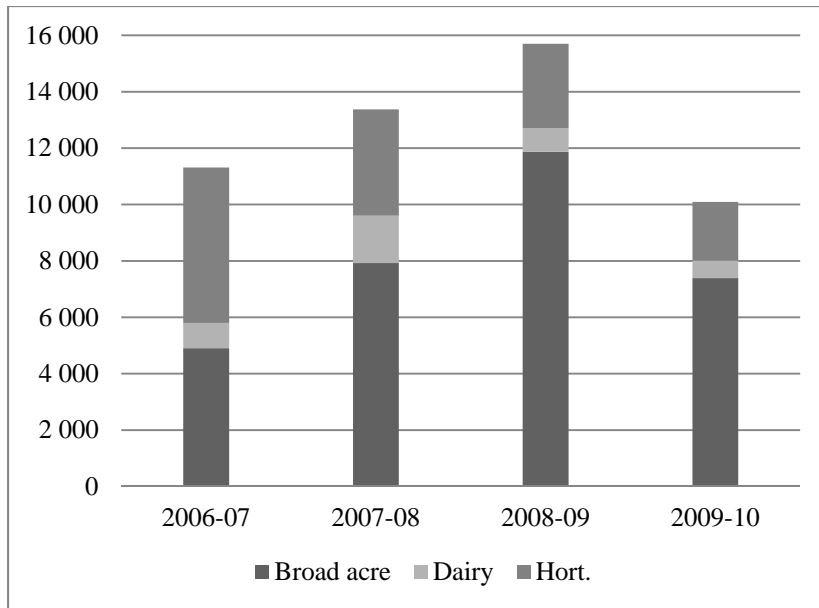


**Figure 1.** The Murray-Darling Basin, Australia (source: Commonwealth of Australia)

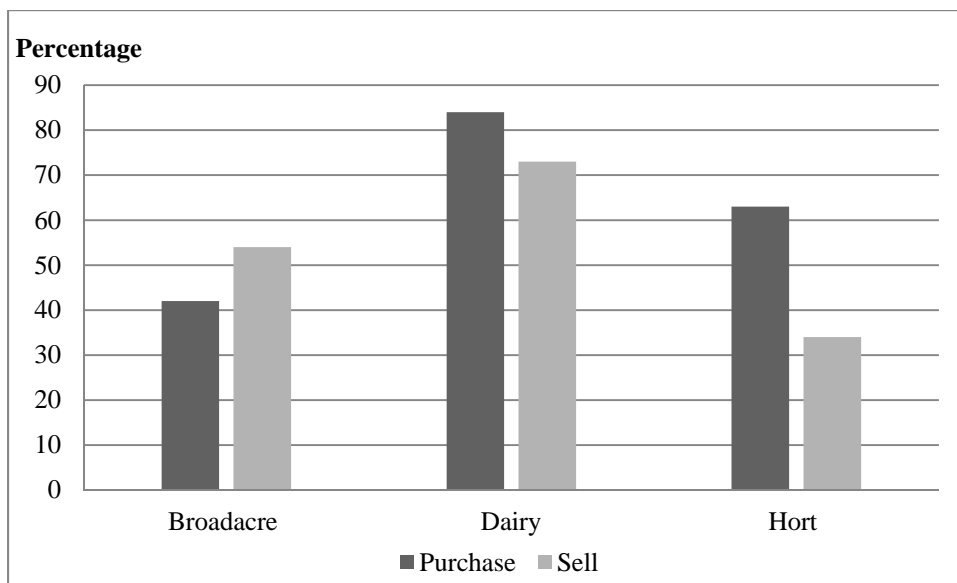


**Figure 2.** Volume of water allocations purchased (ML), by industry and by year (our sample)





**Figure 3.** Volume of water allocations sold (ML), by industry and by year (our sample)



**Figure 4.** Percentage of water allocations that are purchased and sold by water buyers and sellers, respectively from 2006-07 to 2009-10 (our sample)

## Tables

**Table 1.** Mean water allocation price on the market in AUD/ML  
(source: *Waterfind* [2009] and [2010])

Region (State) <sup>a</sup>	Goulburn	Murrumbidgee	Murray (NSW)	Murray (VIC)	Murray (SA)
2006-07	485	194	225	206	202
2007-08	586	723	554	603	620
2008-09	370	343	363	340	352
2009-10	156	194	159	134	139

Note: <sup>a</sup> NSW, VIC and SA are for New South Wales, Victoria and South Australia, respectively.

**Table 2.** Distribution of observations by region and across industries (our sample)

	Broadacre	Dairy	Horticulture	Total
Goulburn	15%	47%	38%	100%
Murrumbidgee	55%	0%	45%	100%
Murray	19%	19%	62%	100%

**Table 3.** Number of farmers trading water allocations on the market, by industry and by year  
(our sample)

	No. of farmers who purchased water allocations				No. of farmers who sold water allocations			
	06-07	07-08	08-09	09-10	06-07	07-08	08-09	09-10
Broadacre	26	14	10	15	17	41	53	31
Dairy	26	19	30	19	9	17	13	5
Horticulture	67	165	85	50	63	42	23	17
Total	119	198	125	84	89	100	89	53
% of sample	31%	45%	38%	28%	23%	23%	27%	18%

**Table 4.** Estimated variance and skewness (averages and mean test significance)

	Second moment (variance)	Third moment (skewness)
<i>Broad acre</i>		
Buyers	10.340***	39.595***
Sellers	4.017	13.374
<i>Dairy</i>		
Buyers	5.426***	-2.401*
Sellers	3.053**	-1.070
<i>Horticulture</i>		
Buyers	12.569*	135.396
Sellers	4.442*	-78.546***
<i>Viticulture</i>		
Buyers	3.942***	3.164**
Sellers	0.130**	-12.908

\*, \*\*, \*\*\* indicates significance at the 10, 5 and 1 per cent level, respectively.

**Table 5.** Volume of water allocations purchased, estimated marginal effects and level of significance (based on bootstrapped standard errors)

Volume of water allocations	Broadacre	Dairy	Horticulture	Viticulture
	Marginal effect <sup>a</sup>	Marginal effect <sup>a</sup>	Marginal effect <sup>a</sup>	Marginal effect <sup>a</sup>
First moment of profit	-6.552	-0.051	-2.855	-5.698
Second moment of profit	8.455**	8.799***	0.832**	6.833***
Third moment of profit	-0.289	-1.231**	-0.039***	-0.263***
Price of beef	-0.024	-	-	-
Price of sheep	-0.071	-	-	-
Price of milk	-	-0.394	-	-
Price of pome fruit	-	-	-0.060**	-
Price of stone fruit	-	-	-0.002	-
Price of citrus fruit	-	-	0.047	-
Price of table grapes	-	-	0.011	-
Price of wine grapes	-	-	-0.013	0.017
Price of vegetables	-	-	0.003	-
Price of other horticulture	-	-	0.000	-
Price of cotton	0.055	-	-	-
Price of rice	-0.211	-	-	-
Price of irrigated wheat	0.015	-	-	-
Price of dry wheat	0.391	-	-	-
Price of other grains	0.003	-	-	-
Area operated	-0.015	-0.090*	-0.013	-0.045**
Number of cattle	-	0.079	-	-
Farm capital	-27.082	70.421	55.705**	-0.125
Price of water	-0.180	-0.033	0.019	0.041
High security entitlement	0.009	-0.074*	-0.015	-0.043**
General security entitlement	0.003	0.020	0.005	-0.085**
Weighted allocation (%)	-1.268	28.074	-50.161**	-100.674***
Debt	11.885	-36.580**	8.256	1.217
Age of the operator	-1.650	0.363	0.353	0.297
Low education level	29.987	-36.097**	-11.080	1.308
Winter rainfall	-0.634	-0.512**	-0.326***	-0.183
Goulburn region	-	-	-	-
Murrumbidgee region	-34.737	-	-56.614***	21.403
Murray region	-73.712	-35.280**	0.700	17.870
No. of observations	385	294	770	286

<sup>a</sup> \*, \*\*, \*\*\* indicate significance at the 10, 5 and 1 per cent level, respectively.

**Table 6.** Volume of water allocations sold, estimated marginal effects and level of significance (based on bootstrapped standard errors)

Volume of water allocations sold	Broadacre	Dairy	Horticulture	Viticulture
	Marginal effect <sup>a</sup>	Marginal effect <sup>a</sup>	Marginal effect <sup>a</sup>	Marginal effect <sup>a</sup>
First moment of profit	26.395***	0.836	-0.967	6.868*
Second moment of profit	-3.241	-0.982	-0.027	-1.393
Third moment of profit	0.499	-0.382	-0.001	-0.031
Price of beef	-0.009	-	-	-
Price of sheep	-0.827**	-	-	-
Price of milk	-	-0.806	-	-
Price of pome fruit	-	-	-0.002	-
Price of stone fruit	-	-	-0.003*	-
Price of citrus fruit	-	-	-0.011	-
Price of table grapes	-	-	-0.006	-
Price of wine grapes	-	-	0.010	-0.019
Price of vegetables	-	-	0.001	-
Price of other horticulture	-	-	-0.004**	-
Price of cotton	0.241	-	-	-
Price of rice	0.313	-	-	-
Price of irrigated wheat	-0.080	-	-	-
Price of dry wheat	0.508	-	-	-
Price of other grains	-0.001	-	-	-
Area operated	0.005	0.028**	0.001	0.005
Number of cattle	-	-0.036	-	-
Farm capital	0.664	9.856	1.947	16.867
Price of water	-0.051	0.057***	0.028**	0.033
High security entitlement	-0.002	0.017	0.023**	0.055**
General security entitlement	-0.004	-0.002	-0.001	-0.003
Weighted allocation (%)	48.780	-16.306	29.850***	40.888**
Debt	9.680	-4.340	-1.313	-4.406
Age of the operator	-1.143	0.199	-0.097	-0.464
Low education level	28.163	-13.323**	-3.795	0.777
Winter rainfall	-0.350	-0.014	-0.070**	0.023
Goulburn region	-	-	-	-
Murrumbidgee region	-8.637	-	17.624**	13.976
Murray region	-53.517*	0.908	-5.106	-11.584
No. of observations	385	294	770	286

<sup>a</sup> \*, \*\*, \*\*\* indicate significance at the 10, 5 and 1 per cent level, respectively.

## Appendix Tables

**Table A1.** Final (end-of-season) high and low reliability allocations in the southern MDB  
(source: NWC [2011])

State <sup>a</sup>	High reliability entitlements (%)				Low reliability entitlements (%)				
	Vic	Vic	NSW	NSW	SA	Vic	Vic	NSW	NSW
Region	Goulburn	Murray	Murray	Murrumb.	Murray	Goulburn	Murray	Murray	Murrumb.
2001-02	100	100	100	100	100	0	100	105	72
2002-03	57	100	100	100	100	0	29	10	38
2003-04	100	100	100	95	95	0	0	55	41
2004-05	100	100	97	95	95	0	0	49	40
2005-06	100	100	97	95	100	0	0	63	54
2006-07	29	95	69	90	60	0	0	0	10
2007-08	57	43	50	90	32	0	0	0	13
2008-09	33	35	95	95	18	0	0	9	21
2009-10	71	100	97	95	62	0	0	27	27
2010-11	100	100	100	100	67	0	0	100	100

Notes: <sup>a</sup> Vic, NSW and SA are for Victoria, New South Wales and South Australia, respectively.

**Table A2.** List of explanatory factors in the moment equations

Variable	Unit	Broadacre	Dairy	Hort.	Wine
Fertilizer	Quantity index	x	x	x	x
Chemicals	Quantity index	x	x	x	
Labor	No. of weeks	x	x	x	x
Irrigation water	Mega Liters (ML)	x	x	x	x
Seed	Quantity index	x			
Cattle	No. of dairy cattle		x		
Fodder	Quantity index		x		
Fertilizer (squared)	Quantity index	x	x	x	x
Chemicals (squared)	Quantity index	x	x	x	
Labor (squared)	No. of weeks	x	x	x	x
Irrigation water (squared)	ML	x	x	x	x
Seed (squared)	Quantity index	x			
Cattle (squared)	No. of dairy cattle		x		
Fodder (squared)	Quantity index		x		
Size of dry land	ha	x	x	x	x
Size of irrigated land	ha	x	x	x	x
Regional dummies		x	x	x	x
Year dummies		x	x	x	x

**Table A3.** List and average values of explanatory factors in the models describing volumes of water purchased and volumes of water sold

Variable <sup>a</sup>	Units	Broadacre Mean	Dairy Mean	Horticulture Mean
Farm cash income	AUD 2010	39 188	51 844	77 715
Farm size	ha	1 881	323	190
Farm capital	1,000 AUD 2010	768.06	816.21	328.06
Price of water	AUD/ML	359	348	377
HS entitlements <sup>b</sup>	ML	82	175	121
GS entitlements	ML	1 296	434	166
Water allocations	%	17	20	38
Debt	1,000 AUD 2010	885.86	873.88	567.39
Farmer's age	Years	55	53	55
Farmer's education	Dummy variable <sup>c</sup>	0.28	0.29	0.33
Winter rainfall	mm	160	187	146

Notes:

<sup>a</sup> The statistics for the commodity prices are not shown here but are available upon request.

<sup>b</sup> HS and GS are for High Security and General Security, respectively.

<sup>c</sup> 1=low education level (no schooling; primary school attended or completed; or 1-4 years high school completed) and 0=otherwise (5-6 years high school completed; trade apprenticeship/technical completed; or university / other tertiary).

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