Sequential decision-making: Theory and evidence for irrigator water allocation trade participation and volumetric choices

Adam Loch

University of South Australia

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Abstract

Greater understanding of irrigator water trade decision-making processes provides insight into the efficient reallocation of water resources between competing uses. Water trade decisions are often modelled as single processes, although results in this paper suggest that sequential decision modelling is more appropriate. We devised a theoretical model of experienced and naïve irrigators based on the search literature, and observed sequential decision-making in water allocation trade decisions using sample-selection techniques. There is evidence of positive selection effects, which motivate different drivers for the decision to participate in water trade and the subsequent decision about how much water to buy or sell.

Keywords: sequential decision-making, sample-selection, water allocation trade, Murray-Darling Basin

1. Introduction

Decision-making by irrigators is important, particularly with regard to water trade. Water trade is one of the main avenues for countries such as the United States of America and Australia to reallocate water between consumptive and environmental uses (Garrick et al., 2009). Water trade also allows irrigators to achieve greater allocation efficiency by reallocating water to higher value uses and provides incentives to enhance technological improvements for efficient use. Therefore, greater understanding of irrigator water trade behaviour and decision-making may improve the total allocative efficiency of water markets. Grafton et al. (2011) compared water markets in Australia, western U.S, Chile, China and South Africa. They concluded that Australia has the most developed water market in the world, and ranks highest in terms of economic efficiency, institutional foundations and environmental sustainability criteria. Studying decision-making in Australian water markets therefore provides key insights for the development of water market in other countries.

Decision-making by irrigators, particularly in regard to water trade, is often modelled as a single-stage rational process (e.g. Wheeler et al., 2010, Griffith et al., 2009). Single-stage rational decision processes often assumes full information and no time-constraints to impede utility-maximization (e.g. Lancaster, 1966). However, economic theory suggests ill-defined and complex decisions are inadequately explained by rational models (Kumar and Subramanian, 1997). Therefore, decision-makers faced with limited capabilities, complex, costly or numerous information resources and time constraints may apply alternative decision rules to improve efficiency (Ariely, 2000).

Irrigators—like other market agents—face search or transaction costs; suggesting analysis of their decision-making is more appropriately modelled as a sequential process. Water trade decisions can be characterized by sequential choices about: i) participation in water trade; ii) buying or selling water entitlements and/or allocations, iii) timing of trade during a season; iv) the mode of trade (e.g. brokered transfer or pooled exchange); and v) volumes of water to be traded. We devise a simple theory using search models and cost-minimising perspectives to support notions of sequential irrigator decision-making. Distinguishing between experienced and naïve irrigators we show cost advantages where water trade participation, reservation price and volume requirement decisions are made sequentially to optimise profit outcomes.

Rather than collecting specific sequential decision-making data we use a unique dataset of water trade decisions by southern Murray-Darling Basin (MDB) irrigators in Australia (Figure 1). The MDB has initiated a wide range of policy and institutional arrangements to reallocate water from consumptive users to environmental needs (Crase et al., 2004). Single-stage censored linear regression model estimates provide a comparison for sequential decision-making via sample-selection model estimates. Our results validate the presence of selective decision-making by MDB irrigators. The findings also suggest drivers for these different decisions and guidance on impacts of government intervention into water markets.

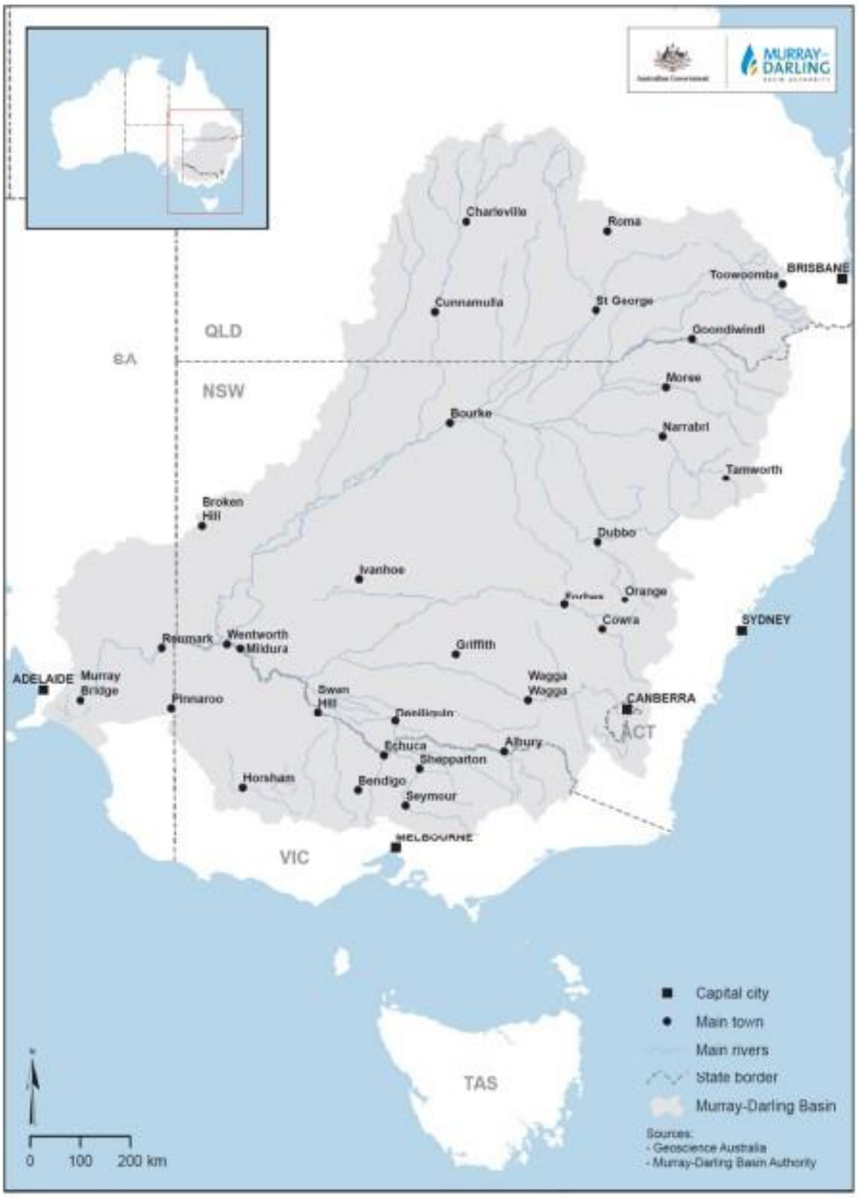

Figure 1: The Murray-Darling Basin (MDBA, 2011a)

2. Water trade in the Murray-Darling Basin, Australia

MDB water resources are broadly characterized as highly variable and over-allocated, with past allocations favouring consumptive uses ahead of environmental (Connell and Grafton, 2011). This past over-allocation, together with a higher social prioritization of environmental flow requirements, has prompted various arrangements to reallocate water between consumptive and environmental uses. Water reallocation arrangements in the MDB generally fall into two categories. First, rules-based approaches under legislative instruments and intergovernmental agreements have been used to identify significant environmental sites and establish riverine environmental flow requirements.[1] Second, market-based approaches have been used to shift water toward higher-valued uses (Goss, 2003), as well as meeting environmental needs (Bjornlund et al., 2011). Water market products include: i) water entitlements, which give users the legal right to take and use water from a watercourse based on seasonal allocations; and ii) water allocations, which is the physical quantity of water assigned each year to the water entitlement holder, dependent on available supply (NWC, 2011a). Although rules-based approaches provide an appropriate reallocation platform, in recent years water markets have been especially effective in reallocating physical water toward the environment under a series of government recovery programs. Irrigators also have the opportunity to donate water (either water entitlements or water allocations) to environmental holdings (e.g. the Healthy Rivers program).

3.1 Australian water recovery

Government water recovery programmes in Australia mainly involve public purchase of water entitlements to reduce the consumptive pool and commit water to environmental uses. The Western US is also using market transactions to achieve environmental objectives in over-allocated rivers and aquifers (Wheeler et al., 2013). Garrick et al. (2011) catalogues 24 US programs for environmental recovery, totalling at least 3000 GL in water contracts. Such market-based recovery programs have increased reallocation of irrigation water to the environment

[1] For example, the Commonwealth Water Act 2007 (Australian Parliament, 2007), state water management plans, sustainable diversion limits to water extraction (CSIRO, 2008) and future Basin-wide planning approaches - exemplified by the proposed MDB Plan (MDBA, 2011c).

(Loch et al., 2012). In Australia, state and federal governments currently own approximately 1,254 gigalitres (GL) of long-term average annual yield water entitlements (DSEWPC, 2012).[2]

Increasing MDB irrigator participation in both water entitlement and water allocation markets has been driven by several events. These include: i) the imposition of a cap on further water extraction from MDB water courses at 1994/95 levels; ii) water market reform announcements under the COAG Water Reform Agenda 1994, which were renewed in 2004 by the National Water Initiative; and iii) an extended period of drought in the southern MDB during the period from 2001 to 2010 (Figure 2).

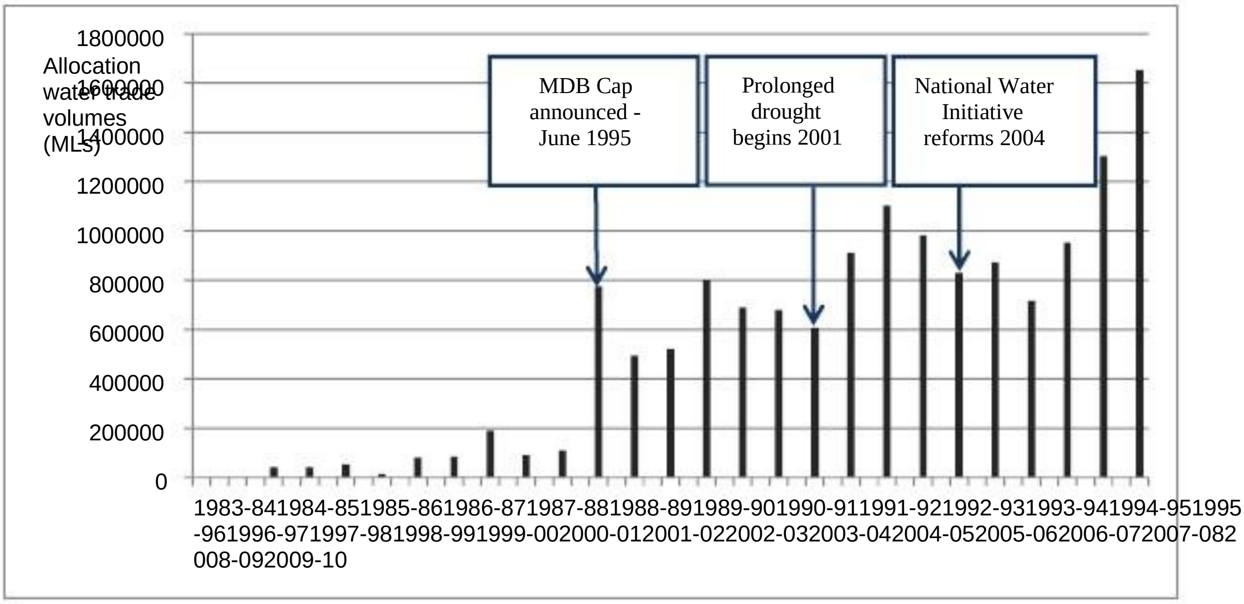

Figure 2: Southern MDB allocation trade 1983-84 to 2009-10 (NWC, 2011b)

Efficient reallocation of water between irrigators in the MDB has also been encouraged through price mechanisms (Brooks and Harris, 2008). However, the normal inverse relationship between price and seasonal allocation levels is complicated by supply and demand schedules for water allocations that shift with the availability of, for example, stored water (Figure 3). With higher water availability (e.g. increased rainfall, water in storages, reduced losses or evaporation)

[2] The long-term average annual yield (LTAAY) is the maximum long-term annual average quantities of water that can be taken on a sustainable basis from MDB water resources as a whole, and from each resource unit (catchment). The Water Act (2007) requires that this reflect an environmentally sustainable level of take (MDBA, 2011b).

irrigator demand for water allocation falls, lowering prices and quantities used accordingly. However, these same availability factors will serve to shift total irrigated water allocation supply outwards, positively impacting allocation trade volumes offered in the market (Wheeler et al., 2008, Brennan, 2006).

Therefore, favourable supply conditions lead to falling water allocation prices, greater water surpluses to irrigators, and indeterminate effects on the volume of between-irrigator water allocation trade. Conversely, poor supply conditions may lead to increased prices and indeterminate effects on the volume of between-irrigator allocation trade. In both cases, the magnitude of the change in price or volume depends on the magnitude of the shifts in supply or demand. As shifts of supply and demand involve non-price factors, this article examines the effects of both price and non-price determinants on water allocation trade decision-making.

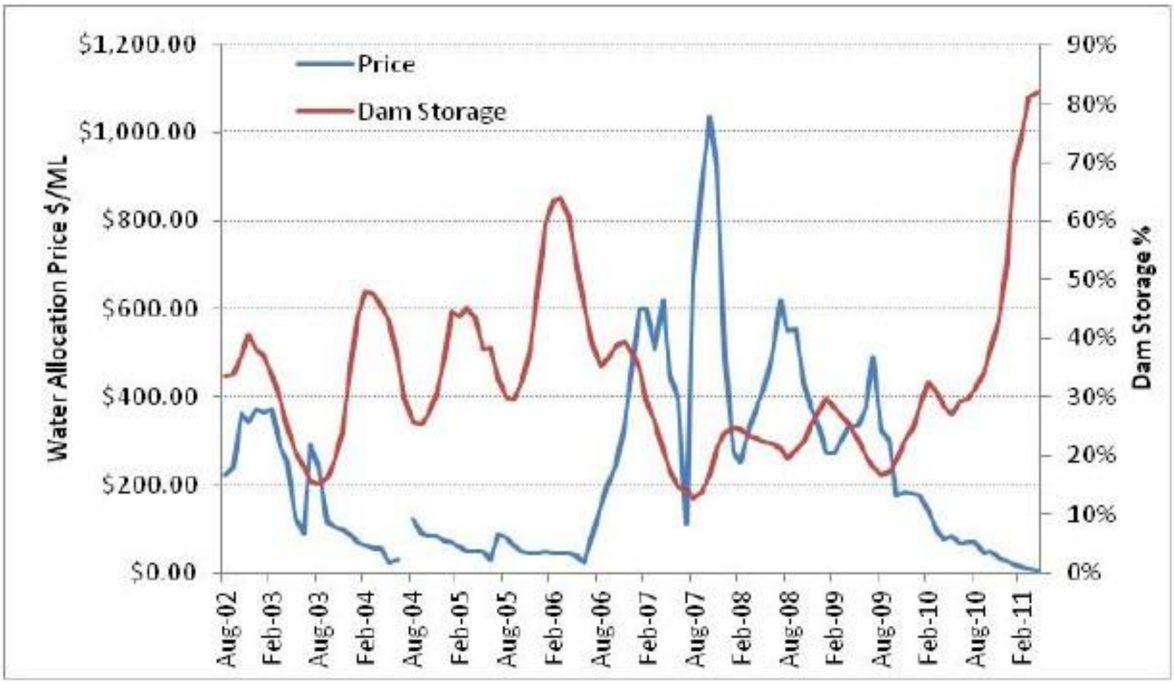

Figure 3: Monthly water allocation prices and mean dam storage levels in the southern MDB from 2002 to 2011

3.2 Irrigation characteristics

MDB irrigation regions are not homogenous in their demand for water. Different agricultural activities have different water demand schedules and price elasticitites, regional characteristics and varied historical determinants for sizes and types of water entitlements owned (Bell et al., 2007). For example, horticultural irrigation water demand is relatively inelastic in the short-term due to the high risk of permanent-planting investment losses if insufficient water is applied. Such constraints motivate water allocation purchasing under reduced seasonal supply conditions, putting upward pressures on price. Conversely, annual crop plantings such as pasture for dairy cattle, can be selectively undertaken based on water availability and the relative difference between water prices and commodity returns/feed prices. This makes water allocation demand for annual crop irrigation relatively elastic (Loch et al., 2012). In addition, irrigators have heterogeneous technical efficiency levels, which alter the benefits and opportunity costs of water use in the MDB. Water markets therefore play an important role in shifting resource use between irrigators with different crop types and levels of technical efficiency.

The information outlined above illustrates some of the complexity expected in water trade choices. There has been little specific research into factors motivating the volume of water allocation traded by heterogeneous irrigators. Understanding these motives is important, as increased volumetric trade may alter demand and supply effects on reallocation through water markets—both for between-irrigator and irrigator to environment transfers. To investigate this issue we develop a simple theoretic model of possible reasons for sequential irrigator water trade participation, reserve price and volume of trade decision-making.

3. Simple theoretical model

The simple theoretical model is based on search literature. A distinction in the literature occurs between random and directed search strategies; where directed individuals observe all potential trade partners in an effort to match their needs. The probability of success is reduced where competition is increased (Moscarini and Wright, 2010). Specifically, we modify directed search behaviour models from Rogerson et al. (2005) to theorize decision-making differences in purchasing water allocations between two types of irrigators: experienced and naïve.

The logic is as follows. Experienced irrigators plan ahead and predict if they will need to trade water allocations during the season. If, for example, they decide to enter the market to purchase water allocations experienced irrigators derive an optimal price for water in the season (taking into consideration commodity prices, predicted inflows and allocations)—and then monitor the water market. Below their optimal price they will purchase a required volume of water to store for future use. An example of this involves carry over, where the irrigator is allowed to retain a portion of unused water allocation for use in the subsequent season. It should be noted that we assume zero storage cost, which broadly matches to within-season carry over arrangements for Australian water markets. In contrast, naïve irrigators fail to plan their water needs ahead, only trading water allocations when they reach a time period where their water requirements become clear/desperate. At that time period, they must buy at the market price. In the simple model below we show that expected costs are lower for experienced irrigators making sequential decisions under a pre-ordained reserve price (R), compared to those of naïve irrigators making simultaneous decisions.

Since the experienced irrigator looks to the future, their objective is to minimize the following cost function of buying water allocations:

(1)

where $\in 0,1$ is the discount factor, c_t is the costs at time t, and E_0 is expectation conditional on information at time $t=0$. For simplicity, we assume $=$, i.e. risk-neutral irrigators.

Next let:

(2) $=$ if accept; 0 if reject

$=$

The water allocation price, p, is distributed i.i.d. and is known by the irrigator. $\leq$, with mean $E(p)$. If a price is accepted, the experienced irrigator buys all the water they need at the given price. We next set $C(p)$ to be the expected cost of paying p at some point in time.[3]

(3) $=$

[3] For tractability, we assume when an irrigator accepts a price p in period t, this is the amount they agree to pay at time t and every period onwards. We can think of these payments as instalments of equal amount at every period.

Note that the above value does not depend on the time that the price is paid. Now set N as the value (cost) of not buying the water. This does not depend on time or which price was rejected:

$$= \qquad ,$$

(4)

$$= \qquad ,$$

Finally, let . B(p) satisfies the following version of Bellman's equation:

$$= \qquad ,$$

(5)

Since C(p) is increasing in p and N is independent of p, there exists a unique R (i.e. reservation price) satisfying C(R)=p, with the following properties:

- P>R implies C(p)>N and thus p should be rejected
- P<R implies C(p)<N and thus p should be accepted.

At p=R the irrigator is indifferent. Thus, the optimal search strategy is to accept any price below R. Since $= 1-$ and , the definition of the reservation price, , is equivalent to , where

$$= \quad \begin{matrix} \leq \\ > \end{matrix}$$

(6)

The reservation price is therefore the solution to the following equation:

$$= \qquad ,$$

(7)

We can then apply the contraction mapping theorem, where we define the mapping as:

$$= \qquad ,$$

(8)

so that there always exists a solution $=$, and the solution is unique. We can subtract from both sides of $= +$ and write the result as:

$$1+ \quad = \quad -$$

(9)

Since $1 - \quad = \quad - \quad =$ and , we get

$$= \quad - \quad .$$

(10)

Equation (10) is the fundamental reserve price equation. It equates the experienced irrigator's cost per period from paying exactly R to the cost from not buying water, which is the discounted expected improvement in next period's offer. The expected cost from using this strategy for an experienced irrigator is $\frac{}{}$.

For the naïve irrigators, the expected cost becomes the market price that they need to pay when they realize the need for water. We can write this price as the average expected water allocation price:

$$=$$

(11)

Similar to the above case, the expected cost for the naïve irrigator is $\frac{}{}$. This, by construction, is more than the expected cost for the experienced irrigator.[4]

It should be noted that for simplicity we considered a stationary environment (infinite horizon) in our theory model. However, the infinite horizon problem can be considered as an approximation to a long but finite problem (Wright, 2000). Moreover, Wright (2000) shows that payments can be a lump sum, rather than per period. Qualitatively, the results shown above still hold. The main difference is that the reservation price would be time dependent, and would increase as we neared the horizon. In other words, the experienced irrigator would consider buying at higher prices as time passes.

So far we have considered an irrigator's decision to purchase extra water. As mentioned above, water trade might also involve selling surplus water. A similar model to the one here can be easily constructed with an irrigator maximising the objective function instead of minimising it.

To summarize, our theoretical model shows cost advantages for experienced irrigators who plan their water trade participation and reservation price decisions ahead of time and make decisions sequentially to optimise profit outcomes. We now return to the MDB context, and use a unique dataset of irrigator decision-making behaviour in an effort to empirically observe decision-making behaviour among irrigators to support our theoretical model.

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[4] It should be noted that the comparison of costs for experienced and naïve irrigators is in expectation, and that it does not rule out the low-probability case of naïve irrigator receiving a lower price than the experienced irrigator pays.

4. Data and methodology

4.1 Data

The data for this analysis was obtained via a telephone survey of MDB irrigators in 2010/11. The survey collected a range of water trade information and socio-demographic characteristics, which were then paired with specific regional characteristics. In total, 946 irrigators were interviewed: 274 in South Australia (SA); 359 in Victoria; and 313 in New South Wales (NSW).[5]

Approximately 50% of the sample did not participate in water allocation trade during 2009/10. After excluding non-participants and missing data, 432 irrigators bought and/or sold allocation water during the period. Table 1 provides definitions and summary statistics for the dependent and explanatory variables used in the estimations.

4.2 Water trade decisions

The modelled water trade decisions include: i) whether or not a MDB irrigator participates in water allocation trade, expressed as a multinomial logit outcome where 0=no participation, 1=both bought and sold water, 2=bought water only and 3=sold water only; and ii) for trading irrigators, the volume of water allocation in megalitres (ML) that they decided to trade. These outcomes are then regressed on a range of determinant variables.

[5] The telephone survey had a total response rate of 37% (including call-backs). Comparisons were made with general MDB farming data to confirm their representativeness. The surveys used computer assisted telephone interviewing methodology, randomly surveying from irrigation organization and commercial farming lists.

Table 1: Variable definitions

Variables	Definitions	Obs.	Mean	Std. Dev.
Dependent variables				
Trade Participation	Trade activity conducted in the water allocation market: 0=no trade, 1=both bought and sold, 2=sold water, 3=bought water	946	--	--
Volume Sell	Actual volume of water allocations sold for season (ML)	223	116.96	189.31
Volume Buy	Actual volume of water allocations bought for season (ML)	209	157.04	248.78
Human capital				
Age	Farmer's actual age in years	940	54.99	10.88
Education	Level of education (1=earlier than year 10, 2=year 10-12, 3=TAFE, 4=University)	946	2.35	0.97
Risk taker	1=if irrigator generally regards themselves as a risk-taker, 0 otherwise	946	0.24	0.43
Farm capital				
Farm size	Farm size (ha)	946	471.47	971.03
Irrigated hectares	Area of farm devoted to irrigated production (ha)	946	144.03	294.38
Employees	Number of full-time equivalent employees on farm, including farmer	946	2.20	2.67
Permanent hectares	Irrigated area in hectares devoted to permanent crops (ha)	946	11.22	42.88
Annual hectares	Irrigated area in hectares devoted to annual crops (ha)	946	123.02	286.29
High water	Total high security water entitlement (ML)	946	294.35	547.83
General (low)	Total general (low) security water entitlement (ML)	946	462.25	1040.8
Water use percentage	Percentage of water entitlement used during the 2009/10 season (%)	946	287.02	639.86
Diverse	Measure of crop diversity where 1=single commodity, 2=two commodities grown etc.	946	1.39	0.82
Farm plan	1=whole of farm plan present, 0=otherwise	946	0.71	0.45
Infra. efficiency	1=irrigator has invested in irrigation infrastructure efficiency measures over last 5 years, 0 otherwise	946	0.72	0.45
Regional biophysical and water market conditions				
NSW	1= irrigator located in New South Wales region, 0=otherwise	946	0.33	0.47
SA	1= irrigator located in South Australia region, 0=otherwise	946	0.29	0.45
Allocation price	Mean regional water allocation price for 2009/10 season ($/ML)	946	184.92	31.56
Allocation	Mean regional seasonal allocation level for 2009/10 (%)	946	43.06	17.36
Net evaporation	Regional net evaporation (evaporation less rainfall) of the respective season from the closest weather station 2009/10 (mm)	946	105.84	19.02
Policy reform				
Carry-over	Actual volume of water carried over from the 2008/09 season (ML)	946	126.93	254.36
Cap	1=if a cap on entitlement trade has prevented water transfer, 0=otherwise	946	0.18	0.38
Embargo	1=embargo effects of trade indicated by irrigator, 0=otherwise	946	0.83	0.38
Balance	Actual amount of water calculated as remaining in water account at end of 2009/10 (ML)	946	168.86	642.03

4.3 Determinants of water trade – independent variables

As discussed, major determinants of MDB irrigators' participation in water allocation trade include prices, variability in regional water availability, capacity of irrigators to adjust short-term farming practices in response to seasonal change, and the expected availability of water during both the current and following seasons. Other influences on irrigator water allocation trade decision-making include: risk-averse attitudes and irrational decision behaviour (Gomez-Limon and Riesgo, 2004); farm income including off-farm sources and commodity prices (Wheeler et al., 2008); farm investments (Bjornlund and Rossini, 2005); farm sizes (Bjornlund, 2006a); and annual versus permanent crop profiles incorporating drought, rainfall, and evaporation rates (Wheeler et al., 2008). Finally, water allocation trade increases have been driven by recent administrative and institutional water market reforms enabling rationalized transfers between trade zones—both within and between states (NWC, 2011a). Recent reforms include carry-over provisions, state-based caps on water entitlement trade, regional allocation water trade embargos and water account balancing rule changes (Loch et al., 2012).[6] The determinant variables are therefore grouped into four categories: i) human capital; ii) farm capital; iii) regional biophysical and water market conditions; and iv) policy intervention.

[6] Carry-over provisions allow water entitlement holders to 'retain' unused allocation water from one season to the next, allowing decision-makers to manage reserve water at their own risk. Availability of carry-over should lead to declining water allocation prices and reduced between-season price volatility (NWC, 2011a). Water allocation trade embargos were introduced in New South Wales during the 2008/09 season to limit the total volume of out-of-district transfers below 70,000 ML. If the limit was reached, sellers would be placed into a ballot to determine successful trades. Embargos should increase allocation water prices and volatility, with indeterminate effects on volumetric trade as demand shifts outwards and supply potentially contracts (Loch et al., 2012). Some southern MDB states also imposed water entitlement transfer caps of between 2% and 4%. Caps may increase the volume of water allocation trade as those committed to, but prevented from, industry exit sell water allocations. Alternatively, removal of caps may reduce volumetric allocation trade as entitlements are sold and accessed by other users (Wheeler et al., 2012). Finally, in 2008/09 South Australia revised water account balancing rules to increase the frequency of excess water use monitoring. Under reduced supply conditions, these changes increased the likelihood of irrigators purchasing water allocations. However, indeterminate effects on volumetric allocation trade would depend on the extent of an individual's excess water use.

Human capital variables include irrigators' age and education level, as well as a dummy variable measuring irrigators' stated willingness to take risk. Farm capital variables include regional dummy indicators for NSW and SA farmers, which should represent major sellers and buyers of water allocations in 2009/10 respectively; leaving Victoria as the default state. In addition, variables such as farm size, the number of full-time equivalent employees and whole-of-farm planning arrangements offer proxies for commitment to farming as a major source of income (Wheeler et al., 2012). Permanent and annual crop measures suggest relative allocation water demand for each irrigator, where ability to meet this demand is influenced by the quantity and security types of water entitlements held. Lastly, diversity in farm operations and previous investments in water efficiency also impact on an irrigator's need to trade water allocations in a season (Wheeler et al., 2010).

Regional differences are captured in the estimates through the incorporation of biophysical and water market condition variables. These focus on average 2009/10 water allocation prices, seasonal allocation levels and net evapotranspiration rates. These factors work in concert to motivate supply and demand in the water allocation markets. Finally, policy intervention variables involve water carried over from the 2008/09 season and dummy variables for the impact of cap or embargo restrictions on trade in the markets. A 2009/10 excess water account balance value calculated for each irrigator provided a proxy for irrigator responses to altered SA account balancing rules. These variables provide the basis for model parameter estimations, as discussed below.

4.4 Estimation procedures

Base volumetric trade decision parameter estimates were calculated using left-censored Tobit regressions on Volume Sell (Buy). With Tobit models, probabilities of non-truncation (i.e. observations > 0) and explanatory variable influences on volumetric trade are calculated simultaneously, potentially biasing the probability and parameter estimates (Sweeney, 2003). In contrast, sample-selection models estimate the probability and coefficient parameters separately, overcoming possible selection bias issues (Vella, 1998). In the two-stage process, initial water allocation trade participation decisions involve four alternatives (i.e. not to trade; to sell water; to buy water; or both sell and buy water). These alternatives provide an unordered categorical variable that can be effectively modelled using multinomial logit (MNL) methods. Two-stage parameter estimations involving MNL modelling can be theoretically attractive—for example, free from irrelevant alternatives (Lee, 1983). Thus, to obtain a first-step estimate of the selection coefficient values that accounts for the polychotomous nature of the individual's decision I_i, a popular approach is to assume that μ_i has a type-1 extreme value distribution that allows estimation of the coefficient values by MNL (Lee, 1983). Like the canonical Heckman two-stage sample selection model using bivariate probit selection processes, our two-stage MNL/OLS approach does not draw the observations randomly from the population; rather an observation is only drawn from the population where the selection variable z^* crosses some threshold. Hence, the selection equation is:

(12)

$$^* = \quad +$$
$$=1 \quad ^* > 0,$$
$$=0 \quad ^* \leq 0$$

And the outcome equation:

(13)

$$= \quad + ,$$
$$, \sim \quad 0,0, \quad , \quad ,$$

is observed only if z = 1. In this case, a bivariate classical normal (seemingly unrelated) regression model applies. The observed trade volume decision (y) and the latent variable under selection (z*) is a function of the observed (x, w) and unobserved (ε, μ) drivers. The standard deviations are σ_ε and σ_μ, and the covariance between the error terms is $\rho\sigma_\varepsilon\sigma_\mu$.

The modelling process involves estimating the MNL under discrete choice conditions, retaining the coefficient values and the asymptotic covariance matrix of these estimates, and then identifying the full set of probabilities. Thus, observations for which z take the discrete value are selected using:

(14)

$$= \quad = \quad \overline{\qquad\qquad}$$

where i indexes the observation, and j indexes the discrete choice or outcome selection. Computed values for the asymptotic covariance matrix (λ_i) obtained using the predicted probability P_i are determined using:

$$= \Omega \qquad , \quad = \frac{\emptyset}{\qquad} \tag{15}$$

This calculation provides consistent ß and θ_j estimates from OLS of y_i on x and λ_j; the appropriate asymptotic covariance matrix. The full regression is therefore stated as:

$$\begin{aligned} &= \frac{\qquad}{\qquad} \\ &= \quad + \quad + \\ &= \quad + \quad + \end{aligned} \tag{16}$$

where the density function $\Phi(t)$ and distribution function (t) are of the standard normal distribution.

Practical examples of MNL/OLS sample-selection estimations that provide advice on the approach are uncommon in the agriculture literature. Wu and Babcock (1998) utilize MNL/OLS estimates to determine the effects of tillage, crop rotation and soil testing practices on economic and environmental outcomes for farmers in the US. They identify two issues with the method. First, a difficulty with interpretation of coefficient values from MNL estimates. This difficulty can be addressed with a calculation of explanatory variable (X) marginal effects on choices. Accordingly, we estimate marginal effects for the MNL component of the two-stage models to improve parameter interpretation and comparison between the models. Second, a lack of robustness is possible where variables affecting the selection decision equally affect the outcome equation, leading to potential multicollinearity. To address this, theory-based alteration of select explanatory variables between each stage is informally recommended (Vella, 1998). Colwell and Munneke (1999) use this approach in an MNL/OLS sample-selection estimation of land-use type effects on price concavity. Similarly, we adjust several explanatory variables between the two-stage estimations. These include: the price of water allocation, which is expected to have a greater impact on the volume of irrigated water used and/or traded in the market (Srinivasa et al., 2000); and general (low) reliability water entitlement holdings, which should change the total proportion of land devoted to irrigation (Brennan, 2006) and consequently the water allocation volume required from (available for) trade. As an additional measure of such effects, total irrigated farm hectares are included as an explanatory variable in the second-stage volume trade outcome models.

5. Results and Discussion

Collinearity issues must be considered with sample-selection models, to determine the appropriateness of full-information maximum likelihood estimators over a limited information two-step Heckman approach (Puhani, 2000). An analysis of multicollinearity with variance inflation factors and a correlation matrix indicated no serious concerns. Therefore, an unordered discrete choice criterion using a multinomial logit full information maximum likelihood technique for the selection is appropriate. Table 3 presents the estimation results for the sell and buy models.

Log-likelihood value comparisons between the Tobit and two-stage models suggest that the two-stage models provide better fitting estimates; a conclusion that is supported by a comparison of Akaike information criterion (AIC) values. Residual standard error values are also smaller in the two-stage models than the estimated standard error of the MNL regression (σ), indicating reduced variance in the error terms (Cameron and Trivedi, 2009) from two-stage modelling. As a limited test of difference, Long and Freese (2006) recommend McKelvey and Zavonia R^2 values from Tobit models as a point of comparison with McFadden adjusted R^2 values. That comparison provides further evidence of better model fit from the two-stage sample-selection approach. Finally, the λ values for the two-stage models are significant, supporting positive selection effects between the two-stages of decision-making. This finding provides evidence of two-stage decision-making among MDB irrigators with regard to participation and volumetric water trade choices (for both selling and buying) during the 2009/10 season, and supports our theoretical distinction between cost-minimising experienced and constrained naïve irrigators. This represents a further contribution towards the better understanding and modelling of irrigator water trade choices. We next discuss specific differences between the single and sequential model outcomes, as well as the implications from a two-stage irrigator decision process.

Table 3: Tobit and MNL/OLS sample selection model results for water allocation participation and volume selling/buying

Capital	Variables	Tobit - Volume Sell β	Std. Err.	Tobit - Volume Buy β	Std. Err.	MNL Sell - 1st Stage Marg. Eff.	Std. Err.	Volume Sell - 2nd stage β	Std. Err.	MNL Buy - 1st Stage Marg. Eff.	Std. Err.	Volume Buy - 2nd stage β	Std. Err.
Human	Age					0.001	0.001			-0.003**	0.001		
	Education					0.010	0.012			0.047**	0.016		
	Risk taker					0.008	0.026			0.132**	0.033		
Farm	Farm size					0.001*	0.001			-0.001**	0.000		
	Irrigated Ha's	0.205**	0.071	0.435**	0.172			0.241***	0.029			0.511***	0.061
	Employees												
	Perm. Ha's					-0.007	0.007			0.009	0.007		
	Annual Ha's					0.001	0.000			0.000	0.001		
	High water					0.000	0.000			-0.000*	0.000		
	General water					0.001***	0.001			-0.001***	0.000		
	Water use												
	Diverse	0.051***	0.011	-0.026	0.046			0.076***	0.010			-0.122***	0.024
	Farm plan					-0.001***	0.000			0.001***	0.000		
	Efficiency					-0.016	0.014			0.038*	0.020		
	NSW region					0.005	0.027			0.062	0.038		
	SA region					-0.042*	0.024			0.024	0.036		
	Price					0.057*	0.090			-0.172**	0.052		
	Allocation					-0.384***	0.042			0.057	0.043		
Biophysical		44.768**	20.961	205.756**	78.200			22.606	34.632			271.929***	
		-32.185	44.531	168.630	140.234			-293.579**	116.579			14.820	140.923
		1.184	0.794	2.908	2.219			2.285*	1.169			0.400	2.099
		2.624**	0.995	4.426*	2.662	0.001	0.001	3.799**	1.547	-0.001	0.007	3.032	2.642
	Evaporation					-0.000	0.001			0.002*	0.044		
Policy	Carry-over					0.001**	0.000			-0.001***	0.000		
	Cap					0.072**	0.027			-0.119**	0.045		
	Embargo					0.069**	0.033			0.069	0.044		
	Balance	-0.096**	0.044	0.051	0.044	-0.001***	0.000	-0.112***	0.023	0.001***	0.000	0.065**	0.017
	Constant	-297.374	195.817	-729.023	564.987	-0.098	0.117	-423.002	312.055	-0.455**	0.182	86.201	554.722
	Observations	202		213			945		202		945		213
Comparative Statistics:													
	Sigma σ (Tobit)	143.200		220.535					—				—
	Residual Standard error (SS)	—		—					119.028				175.776
	Log-likelihood	-1251.10		-1451.59					-1135.87				-1313.03
	AIC	12.858		13.714					1.79				1.79
	McFadden's Adj. R2	—		—					0.5719				0.5242
	McKelvey & Zavonia R2	0.459		0.329					—				—
	Lambda λ (sample-selection)	—		—				-143.3***	34.176			-228.5***	29.927

Note: Significance at the ***0.01, **0.05 and *0.10 levels respectively.

5.1 Between model comparisons

Similarities between the Tobit and second-stage OLS results suggest moderate robustness in the volumetric influences and model specification. Theory-consistent decision-making influences across the models in terms of their direction and magnitude also supports appropriateness of the explanatory variable specification. Full interpretation of the models is arranged according to the explanatory variable groups of human, farm, regional/biophysical and policy capital. Human capital influences on water trade participation act in accordance with previous research findings (Bjornlund, 2006b), which suggest higher education (agricultural) qualifications have positive effects on selling and buying behaviour, while increasing age leads to positive (negative) selling (buying) behaviour. The marginal effects, however, seem to be more pronounced for water allocation buying rather than selling behaviour under 2009/10 scarce supply conditions. This suggests an aging but professional irrigator class (akin to experienced irrigators) committed to productive farming, using water allocation trade to adapt during a period of low water supply to supplement farm production and/or revenue outcomes.

The farm capital variable results provide further evidence of experienced irrigator decisions to supplement farm production and revenue through water trade. Fixed farm capital variables related to the size of land assets, types of water entitlement holdings, past efficiency investments and crop diversity levels drive decisions to participate in allocation water trade. The modelling shows that irrigators with larger farm sizes and greater water entitlements with higher reliability are more (less) likely to sell (buy) water allocations in 2009/10. However, irrigators with greater crop diversity appeared more likely to buy water allocations to support permanent crops with the prospect of higher commodity returns. Further, irrigators investing in measures to improve water efficiency over the last five years are less likely to sell. This may again reflect that irrigators with a farm commitment/protection strategy are more likely to maximize their production with any gains from technical efficiency used to improve production.

Conversely, flexible farm and biophysical capital variables are clearly associated with the decision about how much water to trade in both the Tobit and sample-selection models. This could be anticipated, since they set the physical quantum of water made available. For example, farms with a larger annual crop production and (possible) lower associated commodity returns are less likely to purchase water allocations. Increased allocation levels in 2009/10 motivated the sale of larger volumes of water allocation in the Tobit and sample-selection models. Another important biophysical variable driving the volume of water allocations sold was regional water allocation prices. As predicted by economic theory, generally the higher the regional water allocation price, the higher the volume sold. This outcome was absent from the Tobit results. Prior decisions about seasonal water use and irrigated hectares also appear to be partly linked. Irrigators with a higher 2009/10 water use are less (more) likely to participate in selling (buying) allocation water, explaining the positive volumetric buy decisions in both the Tobit and the sample-selection models.

Regionally, similar positive selling motives for NSW irrigators likely reflect larger farm sizes and higher relative holdings of general security water entitlements, potentially delivering early-season water allocation surpluses. Prevalence of larger farms and general security entitlements in NSW (NWC, 2012) is due to a combination of historical factors. Original NSW irrigation farm settlements tended to be large in size, hold larger water entitlements, and produce annual crops under more flexible annual allocations. NSW irrigators have also tended to maximize their water use each year, rather than secure or carry over water for following seasons. As such, NSW farm operations have been structured to function with less secure water entitlements than Victorian or SA irrigators. There are also significant state differences in irrigator access to dam storage and/or institutional water sharing arrangements, which have occurred over the past few years (Green et al., 2011). Because of these arrangements NSW irrigators received relatively higher allocations early in 2009/10, while SA irrigators received relatively low allocations that increased incrementally over the season.[7] Our modelling shows that an increase in the seasonal allocations associated with general (low) security entitlements positively (negatively) influenced the allocation volume sale (purchase). Thus, one logical NSW irrigator decision in 2009/10 was to forego annual crop production and sell available water allocations at high prices—a finding supported by the sizeable coefficient of the state dummy variable across the models. This also indicates a high relevance of regional location on allocation trade participation. External reports

[7] Previously, NSW generally enjoyed lower seasonal allocation s than Victoria or SA due to more aggressive allocation approaches that applied little emphasis on securing water for following seasons. This was explained by greater irrigator ability to adjust water use from season to season, and a desire to maximize returns this year rather than next (Bjornlund, 2001).

of market behaviour indicate NSW irrigators make large volumes of water allocation available for trade (NWC, 2012), supporting the findings herein.

Policy intervention variables were also statistically significant influences on water allocation buying and selling during 2009/10. Irrigators with higher amounts of carry-over water from 2008/09 were significantly less (more) likely to buy (sell) water allocations in 2009/10. The SA account balancing rule variable was included in both stages on the sample-selection models, with significant negative (positive) impacts on both selling (buying) participation and volumetric decisions. Irrigators who were impacted by trade restrictions, such as caps or embargos, were more likely to enter the water allocation market to sell water, and less likely to enter the market to buy water allocations—albeit only the cap variable was significant in the buy model. This result conforms to modelling in Wheeler et al. (2012), which found irrigators impacted by a trade restriction were more likely to consider (or plan for) selling their water entitlements in the future. Finally, three embargos on NSW out-of-region trade of water allocation in 2009/10 represented a policy aimed at reducing transfers out of NSW. While the appropriateness of this policy may be challenged by our finding of a positive effect of embargoes on decisions to sell, embargo effects were not present during all stages of the season. Therefore, conclusions about embargo policy impacts are difficult to draw. However, our findings lend support to conclusions that embargoes may encourage early (possibly naïve) decisions to sell while opportunities to do so remain (Loch et al., 2012). Part of the importance of our findings stems from measurement of the impact of policy intervention on irrigators' decisions to trade water allocations that, given the relatively novel nature of some of these approaches, have not previously been empirically identified. However, the cross-sectional and limited period nature of the dataset used means that more work is required in this area.

In summary, the identified differences between water trade participation and volume decision-making drivers are interesting for two reasons. First, greater understanding of irrigator water trade behaviour and decision-making helps to increase total water market allocative efficiency, particularly where government reallocation instruments are concerned. Understanding impacts of intervention policies sheds light on useful incentives to increase volumetric trade, especially where water allocation trade offers a key instrument to secure future variable environmental flow requirements. Second, provided evidence of selection effects among MDB irrigator decision-making represents a major contribution towards better understanding and modelling of irrigator water trade choices. Where unbiased parameter estimates are required within complex decision-making frames, two-stage modelling provides an appropriate approach as discussed below.

5.2 Parameter estimation comparisons

The calculation of marginal effects in the first-stage MNL participation model provides readily interpretable and comparable parameter estimates across the models. There are notable differences in the parameter estimates between the Tobit and two-stage models. Naturally, increased probability of selection bias in the Tobit models is likely from self-selecting irrigators into the model on the basis of their trade behaviour. The two-stage model parameter estimates, which account for this selection bias and calculate probability and standard error estimates accordingly, must therefore be preferred. This is especially the case having identified a positive selection effect between the decision-making stages with the lambda-test. Generally, the calculations suggest single-stage modelling may place higher importance on some variables, while minimising the importance of others. Thus, in the estimation and further understanding of irrigator water trade decision-making two-stage modelling appears more appropriate.

6. Conclusion

Irrigator decision-making in water markets is often modelled as a single-stage process, overlooking the inherent complexities associated with water trade choices. We offer a hypothesis that the complex nature of irrigators' water allocation trade decision making—when coupled with volume of trade choices—is more appropriately modelled as a two-stage sequential process through the use of sample-selection techniques. Tobit regression estimates of the influences on the volumetric decision are employed as a source of parameter comparison. The article offers several important findings.

To understand why sequential decision-making may occur among irrigators we develop theoretic models for experienced and naïve irrigators based on search literature. Differences in expected profits between the two irrigator types are shown. These suggest clear advantages for experienced irrigators who plan their water trade and reservation price decisions ahead of time. Next we observe sequential decision-making processes for irrigators making choices about whether to sell or buy water allocations as well as how much water to trade, and compare it to the single-stage process. Empirically, parallels between our theorized experienced/naïve irrigator behaviour can be drawn from MDB irrigator decision-making. We observe a statistical difference between these two decision processes, highlighting the importance of sequential modelling and different drivers in each stage. This is useful, as identification of selective decision drivers and support for a hypothesis of sequential difference between decision stages provides important insights for researchers and policymakers interested in water reallocation and irrigator trade behaviour in water markets. In particular, since trading in water allocation could comprise a key instrument to secure variable environmental flow requirements, the identification of strongly significant and positive influences on irrigator trade behaviour, including the decision about how much water to trade, may offer benefits for environmental water managers.

Importantly we identify different drivers for the decision to participate in trade or not, and the decision about how much water to trade. These include seasonal water allocation prices, announcements of allocation levels, variable rainfall and evaporation rates and more variable supply linked to general (low) security water entitlements. As these variables play a crucial role in establishing the volume of water available for trade, it is appropriate that the models should identify such correlation. Fixed farm capital, regional location and other policy capital variables more likely influenced decisions to participate in water allocation. Lastly, policy changes requiring increased water account balancing in SA during 2008/09 and 2009/10 also prompted statistically significant increases (decreases) in volumetric buying (selling). Inclusion of policy capital variable impacts on MDB water allocation trade in the econometric models is novel in the literature, and the findings identify effective water market policies to influence the volume of allocation water available for reallocation during a given season. These appear to be particularly useful during periods of drought-induced scarcity.

Overall, the findings support arguments that water trade decision-making is complex and sequential and that future irrigator water trade decision-making could be better modelled under a two-stage sample-selection framework. The results of this paper offer guidance to predict the impacts of government intervention on irrigator water market behaviour, as well as providing detail on how irrigators are using water markets to facilitate income and production preferences.

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