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Water policy reform in Australia: lessons from the Victorian seasonal water market*

Donna Brennan†

The nature of the seasonal water market is examined using a theoretical model and empirical evidence from the Victorian market. Drivers of the seasonal opportunity cost of water include the underlying nature of investment in the industry made in the context of risky entitlement yields; and the timing and nature of information regarding seasonal water availability and rainfall. Seasonal water markets facilitate the reallocation of water availability according to this short-run opportunity cost. Evidence from the market suggests that transactions costs are low and most of the existing constraints to trade in seasonal allocations are the result of hydrological conditions. Analysis of market data suggests that the price response of the market to water availability is much more pronounced in years of low rainfall. The implications of the paper for wider policy reform are that attention should be paid to improving property rights for the management of intertemporal risk before other reforms, such as broadening of permanent water markets and institutionalising environmental flows, are implemented. This is because these other reforms will change the spatial and temporal pattern of water use and thus affect reliability, which underpins the value of water in irrigated agriculture.

Key words: irrigation, water markets, water policy reform.

1. Introduction

A decade ago, concern over the environmental implications of continued growth in diversion of water for irrigated agriculture in the Murray-Darling Basin led to the adoption of a policy to enforce a basin-wide limit on future diversions. At the same time, the Council of Australian Governments (COAG) water policy reform process gave financial incentives to state governments, responsible for water resources management in their jurisdictions, to implement an agreed water policy agenda that promoted property right reforms that would facilitate market-based approaches to water allocation.

Two distinct water markets now exist in Victoria and elsewhere in the lower Murray region. One refers to trade in water entitlement, which is the right to a perpetual share of water available for irrigation, and is usually referred to as the 'permanent market'. The other market involves trade in seasonal allocations, and is often referred to as the 'temporary market'. The

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† Donna Brennan (email: donna.c.brennan@csiro.au) is a Senior Research Scientist at the CSIRO Land and Water, and Adjunct Senior Lecturer at the School of Agricultural and Resource Economics, University of Western Australia.

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right to sell water on the seasonal market is based on the ownership of an underlying water entitlement, which yields a seasonal allocation that the irrigator is able to use on his or her own property or sell on the seasonal market.

While water market reforms have been slow with respect to trade in permanent water rights, with severe spatial restriction on trade still evident, temporary water markets have been more broadly embraced by water service providers, irrigators, local communities and state policy-makers. Evidence on the volumes of water traded in Victorian permanent and temporary markets over the past 4 years is provided in Table A1 (Appendix II). The widespread uptake of temporary trade is evidenced by the public water exchanges that now exist to facilitate exchange in seasonal water allocations by providing a public notice board, and sometimes a clearing house, for such trades. The largest of these public clearing houses is Watermove, which began as the Northern Water Exchange that covered temporary trade in the large irrigation districts on the Victorian side of the Murray, and the Goulburn Valley, its major Victorian tributary.

There now exists a substantial quantity of trade data from these temporary markets that can be used to examine the factors affecting the resource value of water in irrigated agriculture, including the nature of long-term and intra-seasonal risk and its impact on water values, the efficiency of the market in price formation, and the relative importance of hydrological constraints on water delivery compared to bureaucratic barriers to trade. A careful examination of the seasonal water market can inform wider policy questions, particularly with regard to the new directions laid out in the National Water Initiative, which aims to continue the market reforms set in place by the early COAG reforms. Much of the national policy attention now centres on getting environmental flow policies in place, overcoming barriers to permanent trade, and continuing the reform of property rights structures to allow greater devolution of decision-making to individuals while protecting third-party impacts.

The agricultural economics profession's work in this area in recent years has moved in concert with the national policy agenda, including Young and McColl's (2003a,b, 2004) work on design of entitlement systems; Freebairn's (2003) and Freebairn and Quiggin's (2006) discussion on the nature of entitlements with respect to reliability; the Productivity Commission's work on water markets (Appels *et al.* 2004; Peterson *et al.* 2004); numerous contributions on environmental flows (Siebert *et al.* 2000; Crean *et al.* 2003; Morrison and Bennett 2004; Watson 2004; Young *et al.* 2002; Qureshi *et al.* 2005); and the Australian Bureau of Agricultural and Resource Economics' (ABARE) efforts across a range of topics relating the water policy (Goesch 2001; Heaney *et al.* 2001, 2004, 2005; Heaney and Beare 2001; ABARE 2002; Goesch and Hanna 2002; Goesch and Heaney 2003; Hafi, 2003).

However, to date limited use has been made of the wealth of information available from the temporary water market. This paper seeks to address this gap by presenting a discussion on the nature of temporary water markets from a conceptual viewpoint and by examining evidence from the market.

The outline of the paper is as follows. In the next section, a conceptual framework is presented that highlights the relationship between the short-run opportunity cost of water and longer-term investment decisions made under conditions of risky entitlement yields. The role of the temporary water market in allocating water to maximise short-run values, and to alleviate intra-seasonal risk is discussed in this context. The discussion sets the scene for the second part of the paper, which examines the empirical evidence on seasonal and temporal values of water from the northern Victorian temporary water market over the seven irrigation seasons 1998–1999 to 2004–2005, including consideration of market efficiency. The paper concludes with a discussion of the lessons learned and their implications for the design of entitlement systems and ongoing market reforms.

2. Theoretical aspects of the seasonal water market

The temporary market must be viewed in the context of the underlying decisions that affect the temporal value of water: decisions that occur over different time frames. These are the long-term capital investment decisions that are made in the context of variable seasonal water availability; annual decisions regarding planting and early-season trade in temporary markets made in the context of expectations over the course of the irrigation season; and production and trading decisions made in response to realised seasonal conditions. The first is the main determinant of the opportunity cost of water; the second is guided by price expectations of the seasonal spot price for water; the third determines the realised spot price at the end of the season when final water accounts are balanced and where irrigators pay heavy fines if diversions exceed allocations. For example, customers of Goulburn-Murray Water must pay if fine of $A1000 for every megalitre of use that exceeds their allocation (that is not offset by a temporary trade).

2.1 The long-term investment decision and the seasonal water market

The short-run opportunity cost of water, which is expressed through trade on the temporary market, is determined by the nature of capital investment decisions that have been made in the industry, which are influenced by the overall reliability of entitlements.

The nature of the capital investment problem in irrigated agriculture under risky entitlement yields, which forms the basis for later discussion on seasonal market values, can be demonstrated using a simple model. The model is based on a model of investment under uncertainty for grain storage (Brennan and Lindner 1991), and examines the nature of the investment problem, as if made by a centralised decision-maker, to achieve the globally optimal value from water-use decisions.

Assume that the quantity of water available in a particular season X_i is defined by a density function $\phi(X_i)$, where $\int_m^M \phi(X_i)dX = 1$, where M and m are the maximum and minimum quantity bounds on reservoir yield. The mean quantity of water available is $E(X_i) = \int_m^M X_i \phi(X_i) dX$.

For ease of exposition, assume Leontif technology, where water requirements per unit of land set up for irrigation are fixed for a particular industry. Let the scale of investment in the industry be denoted by Q_j (representing the volume of water that the industry in geared to use, in this simple model equivalent to the area set up for irrigation multiplied by the water requirement per hectare). The short-run returns to this investment are denoted by V_j per unit of Q_j. The annualised per unit cost of capital, which is incurred regardless of whether irrigation occurs in a particular season, is denoted by K_j.

Reflecting the nature of industries in the lower Murray, denote three industries listed in declining order of capital intensity and decreasing short-run returns to capital: perennial horticulture, dairying and annual crops. Use subscripts H, D and A to denote these industries. The characteristics of the three industries are such that: $V_H > V_D > V_A$ and $K_H > K_D > K_A$.

Because of these economic characteristics, the allocation of water between industries for optimisation of short-run benefits (given sunk investment decisions) is simple, and depends only on level of investment in each industry, and the quantity of water available. In times of scarcity, water will be allocated to the most valuable industry, up to the point where resource demand is met, then to the next valuable industry, and so on. Thus, for a given level of investment in each industry Q_H, Q_D, Q_A, the expected utilisation of capital, defined as μ_j, will be for each of the industries:

Horticulture: $$\mu_H(Q_H) = \int_m^{Q_H} X_i \phi(X_i) dX + Q_H \int_{Q_H}^{M} \phi(X_i) dX$$

Dairy: $$\mu_D(Q_D) = \int_{Q_H}^{Q_H+Q_D} (X_i - Q_H) \phi(X_i) dX + Q_D \int_{Q_H+Q}^{M} \phi(X_i) dX \quad (1)$$

Annual crops: $$\mu_A(Q_A) = \int_{Q_H+Q_D}^{Q_H+Q_D+Q_A} (X_i - Q_H - Q_D) \phi(X_i) dX + Q_A \int_{Q_H+Q_D+Q_A}^{M} \phi(X_i) dX$$

The marginal utilisation of capital at any aggregate level of capital Q_j is denoted by:

$$\theta_j(Q_j) = \int_{Q_j}^{M} \phi(X_i) dX,$$

which is a decreasing (inverse) cumulative density function, such that $\partial\theta_j/\partial Q_j < 0$.

The underlying investment problem is to choose Q_H, Q_D, Q_A to maximise expected long-run profit, defined in annualised terms as:

$$E(\pi) = V_H \cdot \mu_H(Q_H) + V_D \cdot \mu_D(Q_D) + V_A \cdot \mu_A(Q_A) - K_H \cdot Q_H - K_D \cdot Q_D - K_A \cdot Q_A \quad (2)$$

The first order conditions can be found by differentiating with respect to Q_j, the derivation of which is shown in the Appendix II are:

$$Q_H \text{ satisfies:} \quad (V_H - V_D) \cdot \theta_H(Q_H) = K_H - K_D$$

$$\text{and } Q_D \text{ satisfies:} \quad (V_D - V_A) \cdot \theta_D(Q_H + Q_D) = K_D - K_A \tag{3}$$

$$\text{and } Q_A \text{ satisfies:} \quad (V_A \cdot \theta_A(Q_H + Q_D + Q_A) = K_A$$

Put simply, the optimal investment in each industry will depend on the shape of the reservoir yield density function $\phi(X)$, and the relative costs and returns of each industry. Investment in horticulture should occur up to the point where the expected short-run benefits of having access to horticultural capital (the difference in annual returns multiplied by marginal utilisation) is equal to the extra capital cost associated with such investment. Investment in dairy capital will occur at lower levels of expected marginal utilisation, up until the point where the short-run premium over annual crops, multiplied by the marginal utilisation, is equal to the capital cost premium for dairy farming over annual cropping. Investment in capital that allows for production of annual irrigated crops will then occur, at declining levels of expected utilisation, up until the point where the additional capital is equal to the expected short-run returns from utilisation of that capital.

2.1.1 Interdependence between dam management, reliability and capital investment

The above considers the optimal investment at the industry level, given a particular reservoir yield density function $\phi(X_i)$. However, as decisions regarding dam management can change the shape of this density curve, it is likely that capital investment decisions and the design of water rights system are jointly determined. For example, in Victoria, dams are managed to ensure a rather truncated cumulative density function where full entitlements are received in 95 per cent of years, which allows for the investment in substantial perennial horticulture and dairy industries.

A second point to note is that, because decisions about current use X_i are linked to future water availability via dam carry-over, maintenance of the reservoir yield relationship (hence protection of investment assets) requires strong control over seasonal use X_i. In practice, allocations are not managed that strictly in Australia: seasonal allocations represent only an upper limit on allowable diversions, which differ from actual diversions (the total quantity X in season i). The distinction between seasonal allocations and diversions is illustrated in Figure 1. Any change in policy that might lead to an increase in the proportion of allocations that are diverted will change the nature of the reservoir yield function $\phi(X_i)$, with consequences for the expected returns to long-run investment decisions.

2.1.2 The temporary market for the allocation of X_i

So far, the optimal type of investment under uncertainty has been considered from a system-wide perspective, but in reality decisions are made by individuals.

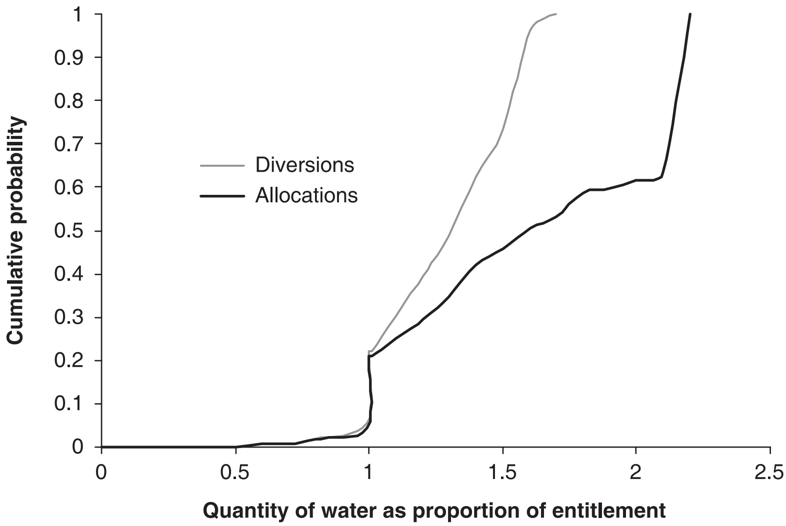

Figure 1 Difference between seasonal water allocations and diversions.
Source: Calculated from data provided from the REALM model of the Goulburn system (James *et al.* 1996; Perera and James 1999).

Other factors not considered here lead to specialisation of farming, so that holders of entitlements might be either horticulturists, dairy producers or annual croppers. In the Victorian system all farmers hold rights with the same level of reliability, where an entitlement is defined as right to a proportion of the seasonal allocation

The nature of the capital investment decision under risk might indicate that water entitlements should be assigned according to the nature of the industry. For example, Freebairn and Quiggin (2006) suggest that proportional rights are inefficient because they do not account for differences in opportunity cost of water between water uses, and argue for entitlements with different levels of reliability, as used in the prior rights system in the western United States. Adamson *et al*. (2006) present an empirical analysis to demonstrate this point, by quantifying the efficiency costs associated with proportional rights under *the assumption* that temporary water markets are not effective in reallocating water on a seasonal basis. The evidence from the temporary water market can shed light on the accuracy of this assumption.

2.1.3 The seasonal price of water

Returning to the investment decisions implied by Equation (3), the associated marginal opportunity cost of water P_i in season i will be:

$$\begin{aligned} P_i &= V_H \text{ if } X_i < Q_H \\ P_i &= V_D \text{ if } X_i < Q_H + Q_D \\ P_i &= V_A \text{ if } X_i < Q_H + Q_D + Q_A \\ P_i &= 0 \text{ if } X_i > Q_H + Q_D + Q_A \end{aligned} \tag{4}$$

In the simple Leontif technology representation shown here, the seasonal opportunity cost of water is the gross margin on the last unit of irrigation-specific technology used, which depends on seasonal availability, X_i. But this is a short-term consequence of investment decisions that are made in response to risky entitlement yields, and variation in these values are driven by differences in returns to capital. In contrast, gross margin analysis has been taken out of context in numerous Australian studies, whereby differences in gross margins have been used to 'demonstrate' the benefits of broadening permanent water trade. For example, most of the linear programming work on water market reform falls into this category (e.g. Hall *et al.* 1994; Jones and Fagan 1996; Eigenraam 1999; Crean *et al.* 2002). While Gyles (2003) and Douglas *et al.* (2004) have criticised the use of gross margins for valuing water, largely because of the importance of capital cost differentials that are ignored in gross margin analysis, the model presented here demonstrates that differences in short-run returns to water between industries are linked not only to the underpinning capital investment, but also to how these decisions are made in the context of the reliability of water entitlements. Linking these two relationships is essential to understanding the complexity of issues regarding water policy reform.

The model presented here is simple but demonstrates the relationship between seasonal water availability and the associated opportunity cost of water. Relaxation of some of the assumptions would allow variation in the short-run returns to capital with respect to water (e.g. relaxing the Leontif assumption), greater complexity of choices between investment decisions, risk preferences, asset fixity in downstream markets,[1] and other investment risks including downstream commodity prices. In reality, greater complexity in enterprise choice, production technology and differences in farmer characteristics would imply a more smoothly declining seasonal price of water as a function of water availability, but it will still be determined by the short-run value of water at the margin:

$$P_i(X_i) = V_i(X_i), \quad \frac{\partial P_i}{\partial X_i} < 0 \tag{5}$$

Although this result is consistent with the discussion on the nature of the seasonal demand curve for water by Appels *et al.* (2004), it has a different justification. They argue that the main benefit derived by horticulturalists from activity on the water market in dry years is the avoidance of 'catastrophic plant losses'. Yet they provide evidence to suggest that current-year value of returns to horticulture (that is, the gross margin) is \$A1000 per megalitre. Since in the short run there are likely to be limited opportunities for substitution of other variable inputs, this gross margin is a reasonable indicator of the

[1] Investment in both horticulture and dairy also have asset fixity issues at the aggregate level, in the form of marketing infrastructure. The level of investment will be driven by this to some extent, and is likely to be jointly determined with other decisions.

seasonal opportunity cost of water to the farmer, and this *alone* is greater than any price observed on the temporary market. Moreover, it is equivalent to the fine that farmers pay for overconsumption of water in the Goulburn-Murray system. Thus, it can be concluded that in the history of the seasonal water market so far, the risk of losses to perennial plantings has not been a driver of these water markets. Rather, longer-term equilibrium between capital investment decisions and dam reservoir yields ensures that investments in perennial agriculture are secure from catastrophe.

2.2 The temporary market as the arbitrageur of seasonal risk

Given specialisation of enterprises and a proportional rights systems, it would be expected that irrigators with high capital intensity would be net sellers on the seasonal water market in year of higher water availability, and those with relatively low capital intensity would be net buyers. However, the seasonal water market does more than reallocating X_i between irrigators according to the higher-order issues relating to capital intensity described in the above model. It also serves to manage intraseasonal risk.

There are two main sources of intraseasonal risk, which relate to rainfall at the farm and catchment level. In terms of the simple model presented in Equation (5), rainfall on the farm affects the annual opportunity cost of water V_i because irrigation demand is supplementary to rainfall that occurs over the course of the season. Rainfall at the catchment level affects the total quantity of water that can be allocated in a particular season, X_i. Early in the season, allocations are based on the quantity available in the dams at the start of the irrigation season under the very conservative assumption that inflows throughout the season will be at 1 in 100 year drought conditions. These early-season allocations are usually revised over the season as rainfall events in the catchment lead to run-off which supplements the available dam reserves.

The nature of uncertainty in seasonal allocations is illustrated in Figure 2, which shows cumulative probability plots of allocations for the Goulburn River, expressed as a proportion of entitlements. The early-season allocation is more conservative, whereas the late-season allocation is further to the right, implying a larger quantity of water is allocated. The difference between the two curves represents the extent to which allocations are revised over a season.

The public water exchange operates on a weekly basis throughout the irrigation season, and the commodity traded is the right to take delivery of water in the current season. These rights are held to avoid a fine if the irrigator uses more than the quantity that they are entitled to take in the current season, defined as the sum of their seasonal allocation and their net purchases on the market. When trading on the market, a farmer's decisions will be based on *expectations* about seasonal allocations and rainfall, and how the seasonal water price (and input and produce markets) may respond to these seasonal conditions. Based on this general uncertainty over the season, it can be expected that decisions to buy and sell water, and water prices, will vary as

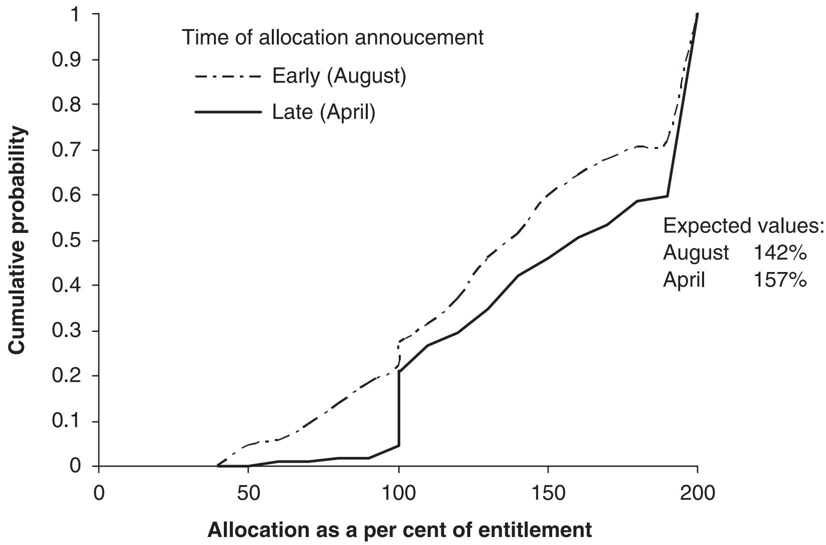

Figure 2 Annual and seasonal uncertainty in the entitlement holder's water allocation. Source: Calculated from data provided from the REALM model of the Goulburn system (James *et al.* 1996; Perera and James 1999).

more information regarding seasonal conditions is revealed over the course of the season. Thus the seasonal market is not really a spot market, but a forward market for most of the season, and it is only when accounts are balanced at the end of the season (and the irrigator risks paying a fine) that the market converges to a spot market, reflecting the realised price of balancing out water-use decisions against the seasonal allocations held.

Differences between farmers will drive opportunities for trade on the seasonal water market, over and above differences in the annual returns from a particular enterprise. For example, differences in their perceptions of and attitudes to intraseasonal climatic risk, and expected seasonal water prices, will affect their willingness to trade as well as the timing of their trading decisions on the seasonal market. If farmers are risk neutral and make trading decisions based on expected water values, we could expect that water prices would decline in relatively wet years and rise in relatively dry years, as spot prices adjust to reflect realised seasonal conditions. On the other hand, if irrigators as a group tend to be more risk averse, the price early in the season may reflect a risk premium above the expected value of water in the season and prices would be more likely to decline over the season as a general rule.

3. The market in practice

3.1 Trade rules, transactions costs and market efficiency

As discussed above, whether or not temporary markets are efficient in allocating water according to seasonal opportunity cost has been questioned. For example, underpinning Freebairn and Quiggin's (2006) model is the assertion that transactions costs associated with temporary markets are greater than the transactions costs associated with designing property rights that reduce the need for adjusting seasonal allocations through the temporary market. Peterson *et al.* (2004) discuss the potential efficiency gains from removing restrictions on temporary trade. Appels *et al.* (2004) concluded that regulations on temporary trade must be for reasons other than hydrological constraints, pointing out that such constraints can be overcome because trade between tributaries can occur via substitution of commitments to provide water downstream of confluences. However, their observation did not account for the fact that opportunities to trade via so-called 'substitution accounts' are severely limited by physical realities. For example, it is impossible to trade 'upstream' into the Goulburn River from the Murray unless there is a significant quantity of water being delivered from the Goulburn to the Murray which can be substituted for. The question of transactions costs and market efficiency can be examined by considering market rules, and financial and other costs incurred from trading on the market.

3.1.1 Financial costs of transactions

The public water exchange provides a market-clearing mechanism and information depository for trade in seasonal water allocations. Each week, farmers can submit offers to buy or sell and must nominate the region to which they want to sell or from where they want to buy. These offers are all checked by Watermove staff for legitimacy (against the rules of trade discussed below), and the market is cleared for each regional pool by determining the intersection of that region's buy/sell offer curves. Information on the outcome and the nature of bids on the market in each weekly pool is available throughout the season via the Internet.

The total volume of water traded on the temporary water market ranges from 10 to 20 per cent of seasonal allocations, depending on location and season. The financial costs of transacting on the public water exchange include a small application fee plus a commission paid by sellers. Financial transactions costs are small, being less than 1 per cent of the cost of buying and about 3 per cent of the revenue from selling.

3.1.2 Market rules and restrictions on trade

Market inefficiencies can arise through unjustified constraints on trade. A close examination of the operating rules of the market reveals that most of the restrictions on trade deal with hydrological constraints. One restriction applies to the total quantity of water that can be traded when allocations are high. This rule requires that the maximum quantity of water that can be sold is 30 per cent, if allocations exceed 130 per cent of entitlements. This rule reflects an intertemporal hydrological constraint. As discussed in Section 2, the distinction between diversions and allocations raises practical problems in the maintenance of reservoir yield. The extension of trading boundaries to

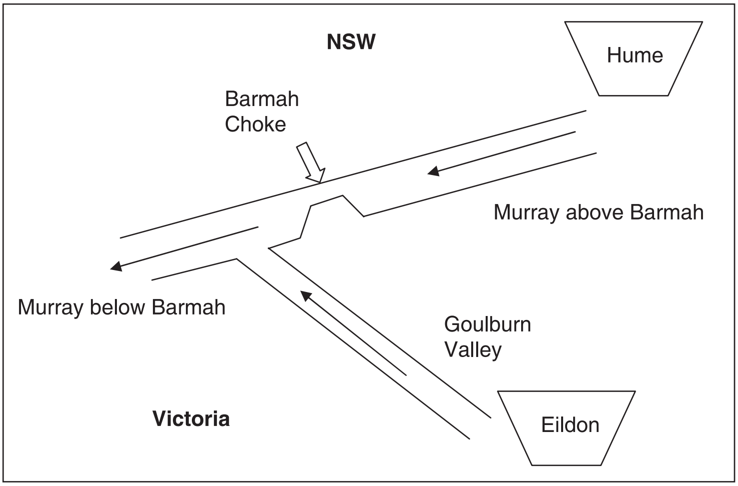

Figure 3 Relationship between three major trading zones on Watermove.
Source: Based on Watermove trading rules: www.watermove.com.au.

a market that was formerly in equilibrium could result in an increased uptake of allocations (measured as the percentage of allocations that are diverted) through increased opportunistic water uses, thus reducing the reliability of system because carry-over would be reduced.

The other main restrictions to trade relate to physical constraints on system delivery. Supply of additional water into the demand region must be physically feasible, either directly or through substitution of downstream flow commitments. Water cannot physically be transferred into the Goulburn system, for example, because it is uphill of the main River Murray. The other constraint is that even if water is physically available in the demand region, the supply infrastructure must be capable of delivering that water in the irrigation season. The 'Barmah Choke' is a delivery bottleneck on the main Murray that has implications for trading from upstream to downstream locations. In addition to these rules, certain salinity and drainage criteria must be met, but these rules do not constrain trade in the regions considered in this study, and so are not dealt with here.

Implementation of restrictions is streamlined through the definition of trading zones. Within a particular trading zone, trades are deemed to be physically feasible and transactions are automatically approved. Transactions between irrigators in separate trading zones are subject to rules and restrictions that reflect physical delivery constraints. The relationships between the three major trading zones discussed in this paper are illustrated in Figure 3, and the constraints to trade between these three zones are summarised in Table 1.

Seasonal price patterns in the market may provide some evidence on the importance of delivery constraints on market prices. Spatial equilibrium theory dictates the price relationships that should exist in the presence of the

Table 1 Trading constraints in the temporary market due to physical factors

Source	Goulburn	Above Barmah	Below Barmah
Goulburn	Trade allowed	Trade allowed	Trade allowed
Murray Above Barmah	Not allowed to trade upstream*	Trade allowed	Restricted delivery through choke*
Murray Below Barmah	Not allowed to trade upstream*	Trade allowed	Trade allowed

* Trade can occur on substitution accounts.
Source: Based on Watermove trading rules: www.watermove.com.au, accessed 10 March 2006.

bottlenecks in the system; these price relationships are shown in Equation (6). Since it is always possible for irrigators in the Murray above Barmah region to buy water from any of the three regions, the price in this region should set the minimum price. On the other hand, if bottlenecks associated with transferring water into the other regions are binding, then prices in these other regions will be higher than this minimum price.

$$P_G \geq P_{AB},\ P_G \geq P_{BB},\ P_{BB} \geq P_{AB} \tag{6}$$

Subscripts in Equation (6) refer to locations: *G* for Goulburn, *AB* for above Barmah and *BB* for below Barmah.

An example of spatial price patterns is shown, for the 2002–2003 season, in Figure 4. Prices for the Barmah-above-Murray zone, which should define the minimum price, are shown in bold. Prices were significantly higher in the Goulburn zone than in the Murray zones, and this can be attributed to the physical constraint that water cannot be traded upstream into a tributary valley. The only way that water could be delivered to irrigators in the Goulburn was from the dam upstream, which was at record low levels. Prices in the two Murray zones were of similar magnitude, although there were some instances where the equilibrium price in the Murray-above-Barmah region was higher than in the region below the Barmah choke. This relationship is inconsistent with the price relationships for an efficient market as depicted in Equation (5), but the price inconsistency tended to only last for a short period before correcting itself. This price anomaly can be attributed to the design of the bidding process. According to the rules and the market clearing mechanism used on the public water exchange, markets are cleared separately in each trading region and irrigators are only allowed to place offers to buy or sell in a single trading region. Thus a grower who is allowed to sell (under the market rules) to two regions may not maximise the value of his or her trade because spatial arbitrage does not occur under this market-clearing process. The market corrects itself after several weeks as information on spatial arbitrage opportunities are made available by the publishing of weekly market prices on the Watermove website, and farmers can change which trading zone pool they submit their subsequent weeks bids to.

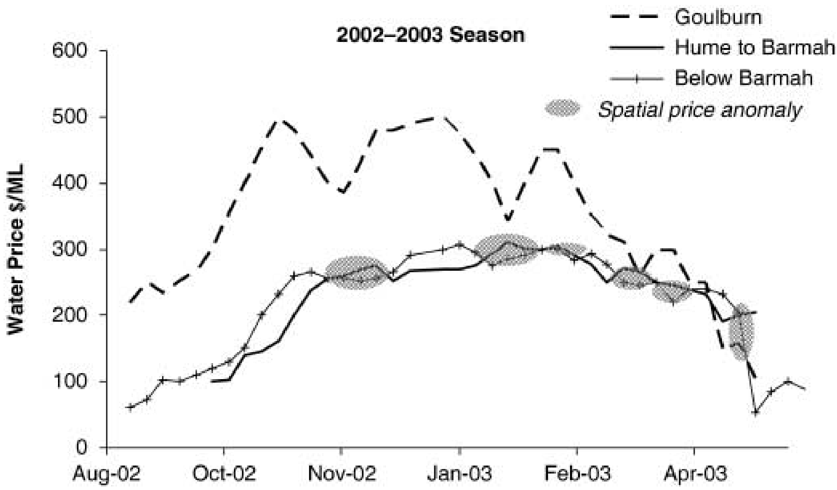

Figure 4 Spatial price patterns for Goulburn and Murray zones above and below the Barmah choke. Weekly market results for 2002–2003 season.

In summary, evidence from the market suggests that the financial and administrative costs of transacting on the temporary water market are small. Spatial limits on trade result in price premiums occurring in some regions, but these are mostly attributed to physical limits on water flow into the Goulburn Valley region. There are some anomalies in weekly market prices that are attributed to the trading rules, but these are small and are corrected as weekly information on market prices becomes available.

3.2 Price movement over the season

The temporal pattern of prices for the Greater Goulburn trading region over the past seven seasons is shown in Figure 5. The breaks in the plotted line mark the periods between the end of an irrigation season and the beginning of the next one. As would be expected, the general level of market prices varies between seasons, as they reflect seasonal conditions, particularly allocation levels. The very high prices in the 2002–2003 season reflect extremely low allocations in that season, which were 57 per cent of entitlements and the only time in history that allocations have been less than 100 per cent.

The pattern of prices over the season is not unlike the price patterns of a commodity futures market. Prices showed a declining pattern in 5 out of 7 years, rose sharply in one case, and rose and then fell in the season in which extreme drought conditions prevailed. Falling price patterns are consistent with risk-averse irrigators seeking to secure water early in the season and paying a premium for such security, after which improved water allocation announcements and/or good rainfall outcomes dampen the spot market for irrigation water. In contrast, a rising price over the season reflects the realisation of bad seasonal outcomes, such as poor rainfall, or unexpectedly low

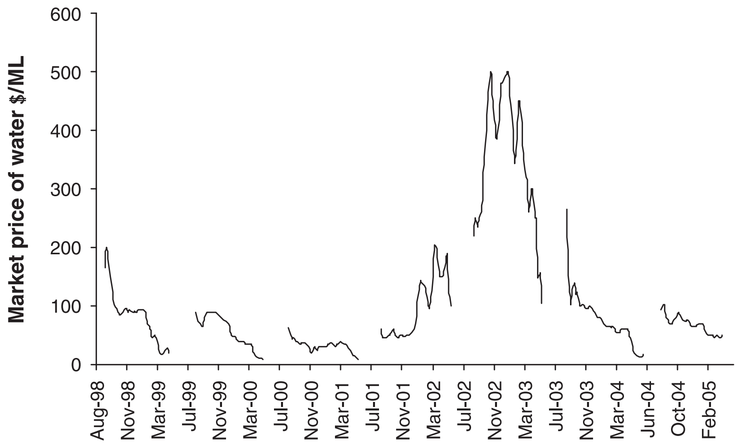

Figure 5 Temporal price patterns for the Greater Goulburn trading zone.

revision of seasonal allocation announcements. The drought of 2002–2003 is a case in point. The extreme peaking of the market is probably consistent with the timing of market news. Allocations are normally close to 100 per cent by the end of October, and allocations had never before failed to reach 100 per cent of entitlements. When allocations remained at 57 per cent with little prospect of revision, the market adjusted to the scarcity by a significant jump in prices. Good late season rainfall contributed to the rapid falling in prices towards the end of the season. The 2001–2002 season is the only example of prices rising toward the end of the season, and this may be the result of extremely low rainfall in the second half of that season.

3.3 Price response in the market

The general model presented in Section 2 and subsequent discussion suggest that seasonal prices should be a function of the total quantity of water available in that season, and climatic factors affecting demand. The hypothesised relationship for seasonal price levels is:

$$P_i = f(X_i, R_i) \tag{7}$$

Trade data from the public water exchange are only available for seven seasons, but market data from both the Murray and Goulburn regions were pooled to provide data for estimation of Equation (7). Pooling the data requires that the shape of the curve is independent of location, which is a reasonable assumption given the conceptual framework in Section 2, and the observation that dams are managed consistently across northern Victoria using similarly conservative rules which result in a similar industry structure between zones, as illustrated by the irrigation enterprise mix shown in Table A2 (Appendix II). This, in turn, implies that as long as differences in scale are

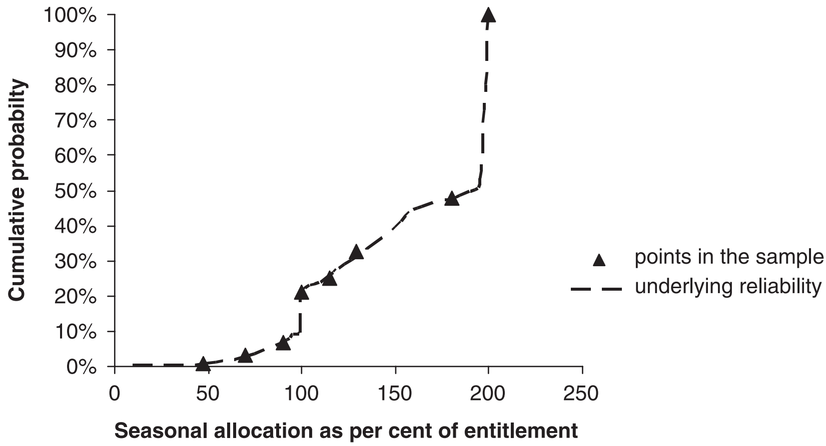

Figure 6 Representation of sample allocations against long-run entitlement yield.

accounted for, the underlying short-run relationship between marginal value and allocations, which is being estimated, is likely to be similar between these regions. Scale differences can be accounted for by expressing seasonal allocations as a proportion of the entitlements. A second requirement for treating the data as independent samples in the two regions is that the price in each region is determined by water availability in that local region alone, and not the other regions. Since the main driver of prices in the Goulburn Valley over the sample period was local allocations, because spatial arbitrage was constrained by hydrological bottlenecks, this is a reasonable assumption.

Selection of the appropriate proxy for X_i is difficult for several reasons. In the simple model presented earlier, X_i is known in a particular year and corresponds to both water availability and water use. In reality, allocations are revised throughout the year, and only provide an upper limit on diversions. Moreover, the revision of allocations over the year is the result of rainfall and therefore is likely to be correlated with local rainfall, which is also a determinant of water prices through the irrigation demand side. A measure of water availability that is statistically independent of irrigation season rainfall is the early-season allocation. This observation was reached after analysis of simulation data provided by Victorian Department of Sustainability and Environment, and can be explained by the fact that early-season allocations are the result of rainfall in previous years, not the current year. In fact, early-season allocations are a proxy for dam carry-over.

The data cover a range of points on the probability distribution for allocations and for rainfall. These data are shown in Figure 6.

With no *a priori* expectations about functional form for Equation (7), regression analysis was conducted for a number of functional forms, and diagnostic tests were conducted. The best result is presented in Equation (8),

$$Ln \text{ Price} = 7.484 - 1.30806\, A - 0.00718\, R \tag{8}$$

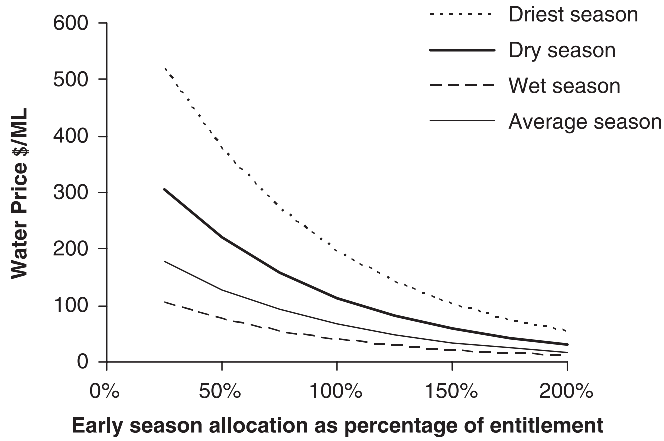

Figure 7 Relationship between seasonal prices, rainfall and dam reserves.

where A is early-seasonal allocation as a proportion of entitlement, and R is total rainfall over the irrigation season in millimetres, using Shepparton data for the Goulburn and Echuca for the Murray.

Dummy variables representing the Goulburn region, and the Goulburn region in 2002–2003 were trialed in the regression but neither was statistically significant. The underlying seasonal factors – allocations and rainfall – were sufficient to explain the Goulburn price rise in the 2002–2003 drought.

This empirical relationship was used to develop Figure 7, which demonstrates the relationship between early-season allocations and water prices, for a range of seasonal rainfall conditions. The dry season rainfall is based on the 25th percentile of the sample data, the wet season is the 75th percentile, and also shown is the predicted relationship for the driest season in the sample. Whereas the extreme points in the sample are estimated with limited data (dry years and low allocations), and are therefore subject to further verification as more data become available, the relationship shown in Figure 7 has important implications for water policy. Results suggest that the effect of reducing allocations depends very much on the seasonal conditions, and the opportunity cost of allocating water for environmental flows will be much lower in years of high seasonal rainfall. This would occur, for example, where medium-term floods are the target of environmental flows. However, one of the impacts of a large allocation to the environment (in order to achieve a medium-term flood) will be reduced carry-over of water and lower allocations in the subsequent year, which would prove costly to irrigators if the subsequent year was a dry one. This result contrasts with the empirical analysis by Heaney *et al.* (2004) of environmental flow policies on the Murrumbidgee in New South Wales, because that analysis emphasises only the current season implications of flow policies. However, this may be a valid assumption in the New South Wales system where dams are not managed as conservatively as in Victoria and irrigation allocations are more closely correlated with current seasonal conditions than past seasonal conditions (via dam reserves).

4. Summary and implications

The conceptual framework presented in this paper demonstrates the relationship between the value of seasonal allocations and underlying investment decisions made in response to risky entitlement yields. The temporary water market plays an important economic role in reallocating seasonal allocations according to seasonal opportunity cost, and in managing intraseasonal risk.

The conceptual model, and the evidence from the seasonal water market, provides reasons for caution against a piecemeal approach to water policy reform that does not take into account the relationships between entitlement yield, long-term investment, short-run values, and spatial restrictions on water delivery. For example, environmental-flow policies that do not account for the value of water in filling dams in high-flow years may result in a costly impact on reliability and erode the value of longer-term investments in the irrigation industry. Similarly, broadening of temporary or permanent trade could result in a disturbance in the spatial and temporal pattern of seasonal water allocations that have formed the basis of investment in the past. Without clearly specified rights to dam capacity, dam inflows, and interseasonal water use, adjustment that occurs as a response to broadening of markets may not be optimal.

Examination of the data from the public water exchange in the Goulburn-Murray region has revealed that the financial costs of these transactions are low, administration is streamlined, and information feeds back into the market. Although there are some price anomalies associated with the design of trading rules, the main drivers of spatial price differences are constraints on trade that are driven by physical rather than bureaucratic bottlenecks. The impact of these physical constraints was a price premium of $A150 per megalitre in the 2002–2003 drought. These physical bottlenecks are also likely to constrain price equilibrium in permanent water markets.

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Appendix I

First, define derivatives of the expected utilisation of capital as defined in Equation (1), with respect to capital, as:

$$\frac{d\mu_H}{dQ_H} = \int_{Q_H}^{M} \phi(X_i)dX \equiv \theta_H \tag{A1}$$

$$\frac{d\mu_D}{dQ_H} = -\int_{Q_H}^{Q_H+Q_D} \phi(X_i)dX \equiv \theta_D - \theta_H \tag{A2}$$

$$\frac{d\mu_A}{dQ_H} = -\int_{Q_H+Q_D}^{Q_H+Q_D+Q_A} \phi(X_i)dX = \theta_A - \theta_D \tag{A3}$$

Similarly,

$$\frac{d\mu_D}{dQ_D} = \theta_D, \frac{d\mu_A}{dQ_D} = \theta_A - \theta_D, \frac{d\mu_A}{dQ_A} = \theta_A \tag{A4}$$

Now the derivatives of Equation (2) with respect to capital are:

$$\frac{d\pi}{dQ_H} = V_H \cdot \frac{d\mu_H}{dQ_H} + V_D\frac{d\mu_D}{dQ_H} + V_A\frac{d\mu_A}{dQ_H} - K_H \tag{A5}$$

$$\frac{d\pi}{dQ_D} = V_D\frac{d\mu_D}{dQ_D} + V_A\frac{d\mu_A}{dQ_D} - K_D \tag{A6}$$

$$\frac{d\pi}{dQ_A} = V_A \frac{d\mu_A}{dQ_A} - K_A \tag{A7}$$

$$\frac{d\pi}{dQ_H} = V_H \cdot \theta_H - V_D(\theta_H - \theta_D) - V_A(\theta_D - \theta_A) - K_H \tag{A8}$$

$$\frac{d\pi}{dQ_D} = V_D \cdot \theta_D - V_A(\theta_D - \theta_A) - K_D \tag{A9}$$

$$\frac{d\pi}{dQ_A} = V_A \cdot \theta_A - K_A \tag{A10}$$

Recalling that $\partial\theta/\partial Q_j < 0$, the following investment decisions arise:

If $(V_H - V_D) < K_H - K_D$ then $Q_H = 0$
else Q_H satisfies: $(V_H - V_D) \cdot \theta_H(Q_H) = K_H - K_D$
and Q_D satisfies: $(V_D - V_A) \cdot \theta_D(Q_H + Q_D) = K_D - K_A$
and Q_A satisfies: $V_A \cdot \theta_A(Q_H + Q_D + Q_A) = K_A$

Appendix II

Table A1 Trade on permanent and temporary markets in the Goulburn-Murray region, 2001–2002 to 2004–2005

Irrigation season		2001–2002	2002–2003	2003–2004	2004–2005
Permanent market: volume of trade as percentage of entitlements (negative means net imports)					
Region					
Greater Goulburn	Trade within zone	0.5	0.9	0.7	0.5
Net trade out of zone*		0.6	0.1	2.9	3.0
Murray above Barmah	Trade within zone	0.3	0.2	0.4	0.4
Net trade out of zone		0.0	0.0	0.0	0.0
Murray below Barmah	Trade within zone	1.3	0.3	0.3	0.6
Net trade out of zone		–1.4	0.7	1.1	1.9
Temporary market: Volume of trade as percentage of allocations					
Greater Goulburn	Trade within zone	19.7	27.9	20.1	20.5
Net trade out of zone		–2.4	–3.1	1.5	–4.4
Murray above Barmah	Trade within zone	3.1	8.6	11.8	14.2
Net trade out of zone		0.0	–1.7	–2.0	–2.9
Murray below Barmah	Trade within zone	5.6	11.2	11.1	11.0
Net trade out of zone		0.9	–1.0	–9.3	–9.0

* Restrictions on trade in permanent entitlements apply to irrigators within irrigation districts, whereas the trade data shown here include trade by river pumpers that are not restricted. In fact, permanent trades out of irrigation regions in the Greater Goulburn area in 2003–2004 and 2004–2005 were bound at 2 per cent according to the trading rules. The volume of temporary trades has increased in this period compared to levels of 5–10 per cent in the late 1990s (Marsden Jacob 1999).

Table A2 Mix of irrigation enterprises in the Goulburn-Murray region in 1996–1997

Trading Region	Total volume of water entitlements in 2004, GL	Percentage of total irrigated area, 1996–1997			
		Horticulture	Dairy	Cropping and grazing	Grazing
Greater Goulburn	945.5	5	46	21	27
Hume to Barmah	593.9	4	53	23	20
Barmah to Nyah	890.0	3	40	18	39

Source: Survey conducted by Goulburn-Murray Water in 1996–1997. GL is gigalitres.