The Australian Journal of
Agricultural and
Resource Economics

Journal of the Australian Agricultural and Resource Economics Society

The Australian Journal of Agricultural and Resource Economics, 52, pp. 471–485

Missing markets for storage and the potential economic cost of expanding the spatial scope of water trade

Donna Brennan†

A great deal of attention has been given in recent years to the question of externalities associated with water entitlements and how third parties can be protected without restricting opportunities for water trade. Yet one market failure that has received no attention at all is the missing market for storage that arises from the specification of water entitlements, particularly in Victoria where historically all storage decisions were made at the centralised level and where any additional carryover was treated as common property. The economic significance of the missing market for storage is demonstrated using an empirical model that represents the spatial-temporal pattern of irrigation water demand in the Goulburn Valley and decisions regarding inter-year storage of water in Lake Eildon. It is shown that, because irrigators have no incentive to trade-off the benefit of current use (or sale) with the value of water storage, there is an erosion of reliability when opportunities for trade are broadened. The empirical results demonstrate that the loss in economic value associated with reduced reliability are as large as the gains from trade, so there is no net benefit from trade.

Key words: drought, storage, water markets.

1. Introduction

After a decade of economic reforms in the irrigation sector in Australia, opportunities for trading seasonal water allocations and more recently permanent water entitlements between valleys and between states in the lower Murray Darling system are now enshrined in legislation and in policy. Impetus for trade in irrigation water rights was with the implementation of the Murray Darling Basin 'Cap' which set an enforceable limit on aggregate irrigation diversions. Water legislation was rewritten to better define water property rights and practical procedures for implementing water trade were gradually developed. This policy evolution was assisted by substantial commentary and debate from the agricultural economics profession, with much of the discussion centred on methods for overcoming externality problems associated with trading a poorly defined property right (e.g. Brennan and Scoccimarro 1999; Beare and Heaney 2002; Marsden 2002; Young and McColl 2003; Goesch and Beare 2004; Heaney *et al.* 2006).

† Donna Brennan (email: donnabrennan@iinet.net.au) is an Adjunct Senior Lecturer, University of Western Australia & Visiting Fellow Australian National University, 12 Galwey St, Leederville, Western Australia 6007, Australia.

doi: 10.1111/j.1467-8489.2008.00443.x

The enthusiasm for improving water resource allocation over space was not matched by attention to the inter-temporal resource allocation problem, and even today the definition of private property rights to storage is weak or non-existent, depending on the state. In the New South Wales system, which historically had a policy of releasing available dam water each year and providing little centralised storage, irrigators have had (restricted) rights to carryover water allocations between seasons since 1999. South Australian irrigators have no access to storage. In Victoria, there has historically been no carryover policy and unused seasonal allocations became common property at the end of the irrigation season. However, the Victorian system has an explicit centralised storage regime which is aimed at providing a high level of reliability to water entitlements.

The focus of this article is on the storage regime that was historically used in Victoria. It should be noted that recently the Victorian government has introduced limited rights to carry-over water, the empirical analysis does not consider this new modification to rules. Rather, the analysis focuses on the impact of broadening the spatial scope of trade when a centralised storage regime is in place. The results are relevant to the policy that was in place over the past decade up to 2005–2006, and also serve to demonstrate the problems associated with failure to consider the economic role of storage in a complex system like the lower Murray. When a centralised storage policy is in place, broadening the spatial scope of markets provides greater opportunity for use of current season allocations and greater uptake of current season allocations which can result in less storage and an erosion of reliability. Results are compared to the spatial and temporal resource allocation that would be achieved from a competitive storage market.

The article is organised in five additional sections. In the next section, a graphical presentation of the economics of water storage and the missing market associated with current entitlement structure in Victoria is presented. Section 3 describes the empirical model used to derive the results presented in Section 4. The final section contains a discussion of the implications of these results for policy formulation, and the future research needs in this area.

2. Graphical presentation of the missing markets problem

The nature of the river and irrigation infrastructure in the lower Murray is such that storage performs two main economic functions. One is intra-year storage which involves transferring water from the winter–spring inflow period to the summer–autumn demand period. The other is inter-year storage, which is the function of transferring water from high inflow years to low inflow years. It is this second function, the management of inter-seasonal risk, which is the focus of this analysis.

The physical nature of the decision making problem is depicted in Figure 1. For simplicity the year is divided into two periods, the inflow period and the use period. In reality around 20 per cent of inflows occur in the irrigation

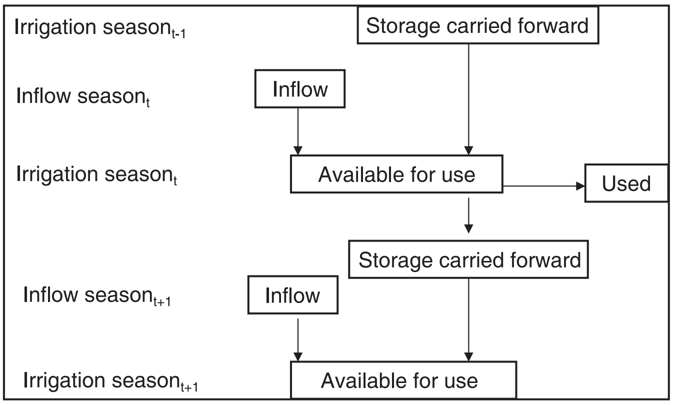

Figure 1 The decision making problem.

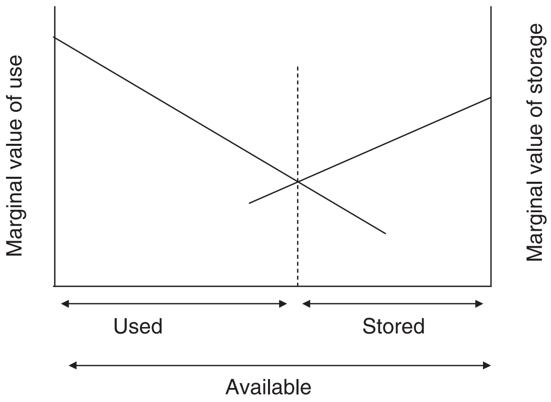

Figure 2 The efficient storage equilibrium.

season and allocations are revised over the first few months of the irrigation season to reflect these changes. However, the simplification captures the essence of the risky decision problem and provides for ease of discussion. Water available for use in the current irrigation season depends upon the quantity of inflows into the dam since the previous irrigation season and the amount of water carried forward from the previous irrigation season as storage. The available water can either be used in the current irrigation season, or left in the dam and carried into the next season.

The economic trade-offs are demonstrated in Figure 2. The horizontal axis shows the total amount of water available which has to be allocated either to consumption or to storage. The vertical axis on the left, and the downward sloping line that intersects it, depicts the demand for use in the current period. The vertical axis on the right and associated curve depicts the expected marginal value of storage. Moving from right to left on the diagram depicts a greater amount being allocated to storage, and the marginal value of this storage is declining. The reason for this is that the marginal value of storage mirrors the expected demand curve in subsequent seasons, which is downward sloping. While the realised value of stored water will depend on inflows that are currently unknown, a greater amount of storage will have a lower value at the margin, no matter what the inflow period delivers. It is the trade-off between these two curves that determines the optimal inter-temporal equilibrium between consumption and storage.

The storage problem can also be described mathematically, according to the inter-temporal arbitrage conditions drawn from the commodity storage literature (e.g. Williams and Wright 1991). These are the first order conditions for maximising the expected value of inter-temporal consumption and for the water storage case can be describes as follows:

$$P_t(S_{t-1} + \tilde{I}_t - S_t - D_t, \tilde{R}_t) \geq \frac{1}{1+r} E_t[P_{t+1}(S_t)] - k \tag{1.a}$$

$$S_t \geq 0 \tag{1.b}$$

$$\left(P_t(S_{t-1} + \tilde{I}_t - S_t) + k - \frac{1}{1+r} E_t[P_{t+1}(S_t)]\right) \cdot S_t = 0 \tag{1.c}$$

Where, P_t is current period price $E_t[P_{t+1}]$ is the current expectation of next periods price, S_t is amount carried out of period t, I_t is random inflows, D_t is delivery losses between the dam wall and the irrigator, R_t is irrigation season rainfall, k is the physical cost of storage (i.e. evaporation losses and costs of operating the storage) and r is the discount rate. For simplicity, the value of water in the current period is expressed as the value of water at the dam wall. Losses between release and consumption are accounted for in the hydrological model.

The left hand side of equation 1a is the current period demand for water or opportunity cost of storage, and the right hand side is the marginal benefit of storage net of storage costs. Several points are worth noting. First, the arbitrage conditions are met as an inequality because storage cannot be negative, and this means current season prices can greatly exceed typical prices in periods when stock-outs occur (Williams and Wright 1991), a phenomenon that is well known in commodity markets and has been observed in recent years in the lower Murray water markets. Second, the right hand side of the equation is the expected marginal value of storage, which depends upon the outcome of future risky events and subsequent decisions. The only thing that is 'known' about the expected future value of storage is its relationship to the quantity stored, although for empirical analysis this must be estimated using stochastic dynamic programming techniques. In contrast, demand conditions in the current period (and hence optimal amount stored) will depend upon the overall availability of water and climatic conditions.

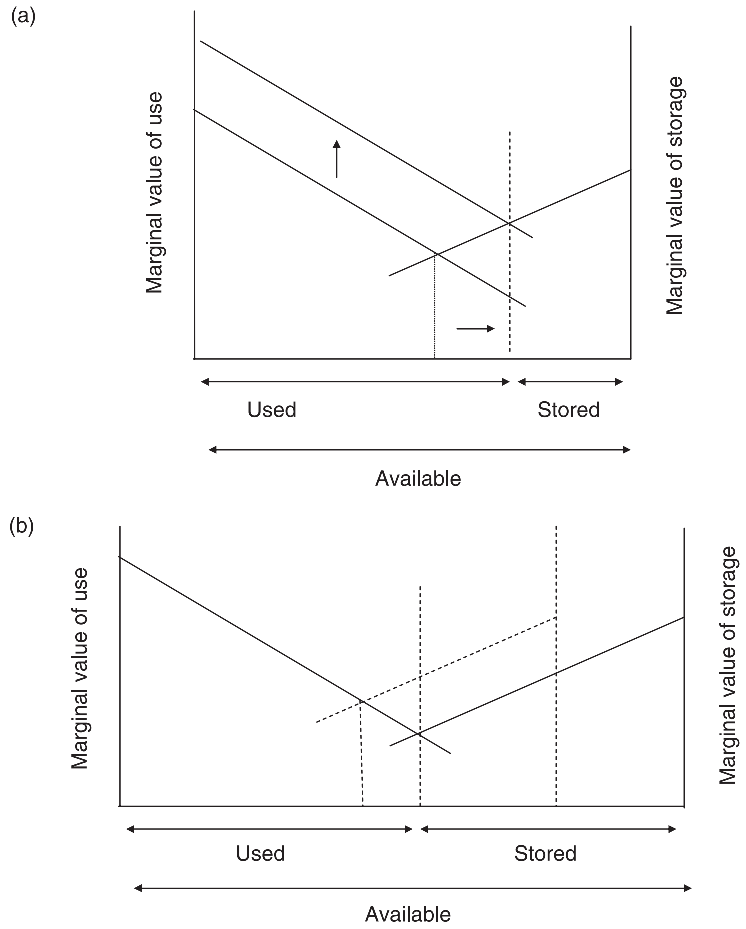

Figure 3 (a) Impact of a hot dry irrigation season (upward shift in current season demand) on storage and use. (b) Impact of high availability on storage and use.

Availability depends on the realisation of last winters inflows; whereas climatic conditions include irrigation season temperature and rainfall, which define evaporative water demand. The impact of high water availability and hot dry irrigation season conditions on optimal storage are depicted in Figure 3(a,b).

The marginal value of use will shift upward under low rainfall conditions, resulting in relatively more use and less storage at a given level of availability, as shown in Figure 3a. Similarly, under high rainfall conditions current season demand is reduced and a greater quantity should be stored. When there is relatively more water available, either as a result of storage decisions made last period or high winter inflows, additional water is probably allocated to both storage and use, depending on the relative positions of the marginal benefit curves as shown in Figure 3b.

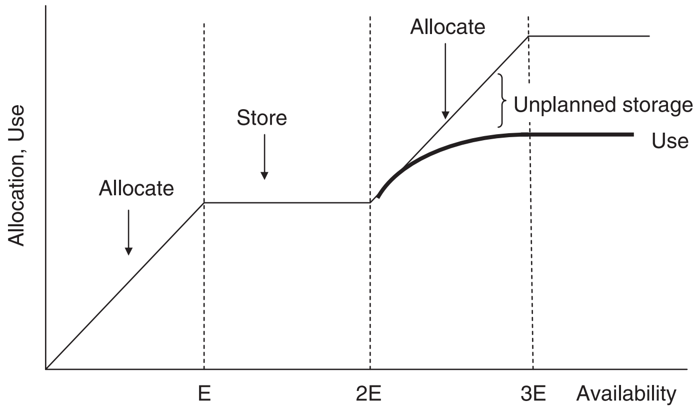

Figure 4 The seasonal allocation rule and associated pattern of water use, Victorian storage regime.

2.1 Water storage in the current entitlements system

In Victoria, fixed decision rules govern the allocation of available water between current use and storage. Storage carried out of an irrigation season is the sum of a deliberate reserve policy, plus a residual amount made up of unused seasonal water allocations. The water allocation decision depends largely on water availability, as depicted in Figure 4. Specifically, the dam release rule requires that if available dam reserves exceed the aggregate entitlement volume, then this extra water is set aside as a reserve for next year's supply up until the point where water stored is equal to 100 per cent of entitlement. If available reserves exceed twice the entitlement, then additional water can be allocated to irrigators in the current season. The maximum allocation is 200 per cent of entitlement. If available dam reserves are less than the entitlement volume, then all available water is allocated to the irrigation industry in the current year and entitlements are not fully met (James *et al.* 1993).

Whilst allocations can be up to 200 per cent, at high water allocations the actual level of water use is substantially less than allocations. The low marginal uptake at high allocations is probably the result of rational long term decisions regarding the expected utilisation of capital under seasonal risk. For example, it would not be efficient to invest in additional channel delivery capacity or additional irrigation specific capital on the farm, to use additional quantities of water that might only be available infrequently (Brennan 2006). By default, this unused water is placed into storage.

Under the Victorian entitlement structure, some of the risk associated with variable inflows is removed by the engineered storage policy, but there is no capacity for farmers to modify the quantity stored to satisfy their own reliability requirements, because the unused water is returned to a common pool at the end of the irrigation season. Even if the irrigator has a private value associated with storage as shown in the dashed line in Figure 5a in the absence of clearly

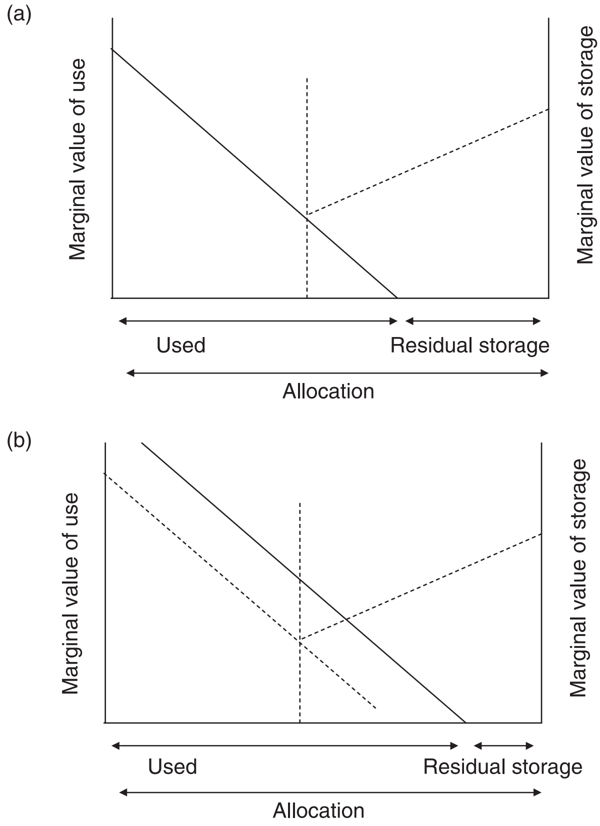

Figure 5 (a) Residual storage in a market with no private property rights to storage. (b) The impact of trade on current period demand and residual storage.

defined property rights over that storage the irrigator will use (or sell) seasonal allocations in the current period until all the current season rents are dissipated.

The problem with introducing spatial markets is that it increases the opportunity for current season use and therefore reduces the ‘residual storage’ that occurs with the current entitlement structure, as illustrated in Figure 5b. As long as there exists some opportunity for using water in another location under circumstances where current use opportunities in the original location are low, there will be an increase in current period use and a reduction in residual storage, hence an erosion of reliability.

3. Modelling the impact of market expansion on storage and gains from trade

The estimation of the cost of the missing market for private storage is problematic because in theory, the dissipation of rents would have begun as soon as any trade (even within valley) became possible, because it would have allowed for greater use of water for opportunistic cropping on farms set up for that purpose, and thus reduced residual storage. Price data derived from seasonal water markets can indicate the current aggregate demand curve for water, but it will exhibit a progressively longer tail (or low value elastic component) over time as markets are broadened and greater opportunities are available for low valued opportunistic uses. In this study the aggregate demand curve for the Greater Goulburn is drawn from analysis reported in Brennan (2006) which was based on data from 1998 to 2004, during which time there was already a tendency for a net movement of water out of Goulburn into the Victorian Murray system below Barmah. This analysis examines the impact of an expansion of trade in seasonal allocations into the NSW Murray, and therefore does not capture the erosion in reliability that may have been associated with increased intra-state trading opportunities. The analysis of the seasonal water market trade can also represent a permanent 'tagged' transaction between a Goulburn and NSW irrigator, where the NSW irrigator only used the water in NSW if the expected value of use was greater than that value that could be obtained by making it available for sale on the Goulburn seasonal market. The empirical model used to estimate the economic impact of expanding water trade is presented in the remainder of this section.

3.1 Evaluation of alternative storage policies

To demonstrate the nature of the missing market problem, the analysis is conducted for two storage policy scenarios. One scenario represents the existing entitlement structure where storage is the sum of centralised storage decisions plus the common property unused allocation. The other scenario represents a competitive storage market where decisions about use (including trade) are balanced against the expected value of storage (the right hand side of equation 1a), which is estimated from a dynamic stochastic programming model. The expected value function was estimated using the parameter iteration method (Williams and Wright 1991), where the expected value function is estimated as a polynomial function of the quantity stored. A detailed description of the solution method is provided in Brennan (2007). The process involves estimating, for a range of incoming storage levels, the expected price that would be realised if the approximation equation for the value of storage were used to allocate between current season and the future use. This calculation is done over the range of possible climatic outcomes represented by a discrete probability distribution. The model is solved repeatedly until the estimated value curve converges with the realised value of storage.

3.2 Representing the hydrological system

The hydrological system is modelled in a spreadsheet using the historical series on inflows into Lake Eildon from 1881 to 2004, using a time step of one month during, the May to October period when 80 per cent of inflows occur, to better account of dam spillage associated with variable monthly inflows that might not be captured in an annual time step model. The distribution of

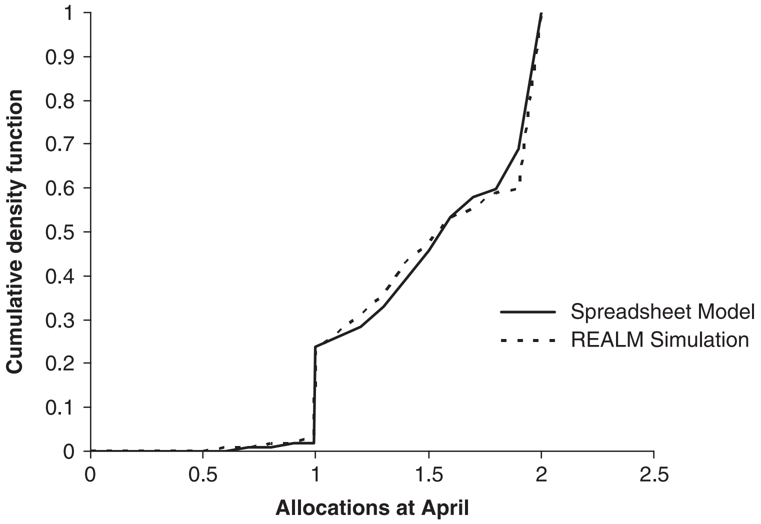

Figure 6 Comparison of simulated allocations under spreadsheet model.

currently available water between 'seasonal allocations' and 'deliberate storage' was based on the decision rule illustrated in Figure 4. One of the main difficulties in modelling the current entitlement system is modelling the uptake of those seasonal allocations (hence residual storage). Because of the existence of constraints on delivery, and the option value of holding water during the irrigation season in the event of a dry finish, there is no reason to expect that water will be used up to the point where the realised market price is zero. Instead, the simulation model draws on key relationships in the Victorian government's REALM model of the Goulburn River (James *et al.* 1993) which uses a set of equations to represent the uptake of current season allocations according to irrigation season rainfall and the volume allocated. The simulated probability distribution of water allocations in the base case (current policy), which uses the dam release rule to determine seasonal allocations, correlates well to the probability distribution of water allocations simulated from the REALM model, as shown in Figure 6.

The expanded trade scenario, simulated for the existing storage policy, assumes the same pattern of uptake of water for use in the Goulburn Valley, but in addition simulates opportunities to trade water to NSW irrigators. For the optimal storage policy, these decisions regarding trade are determined by the inter-temporal arbitrage conditions where the current period opportunity cost includes opportunities from trade.

3.3 Current season water values

The current season value of water for the Goulburn system was derived from results reported in Brennan (2006) which describe current season water prices as a function of irrigation season rainfall and seasonal allocations. This equation was combined with the empirical relationship between allocations and diversions described in the previous section to define an irrigation demand equation, as shown in Equation (2). Results in Section 4 represent the area under this demand curve.

$$P_t = \exp(8.100 - 6.92 \times 10^{-3} R_t - 2.33 \times 10^{-6} Q_t). \tag{2}$$

Where, P_t is price of irrigation water in season t; Q_t is quantity consumed by irrigators (diversions – delivery losses), mL; and R_t is irrigation seasonal rainfall in mm.

To represent the potential demand for water from the NSW Murray, a similar model was estimated using data reported on the Murray exchange.[1] An historical time series of NSW Murray allocations, together with rainfall at Deniliquin, were then used to generate the marginal (pre inter-state trade) price in New South Wales. The slope of the trade demand function was derived by adjusting the coefficient for allocation in Equation (3), to represent volume rather than per cent.

$$P_t = \exp(6.52 - 5.398 \times 10^{-3} R_t - 2.439 \times 10^{-4} W_t). \tag{3}$$

Where, W_t is allocation in the current year as a proportion of entitlement.

In the simulations where trade with NSW is allowed, it is assumed to only occur in one direction (from Goulburn to NSW) reflecting current trading rules associated with system delivery constraints. The quantity of trade was determined by the solution to the spatial equilibrium. In the case of the optimal storage simulations the spatial and temporal equilibria were solved simultaneously.

4. Results

The expected annual value of water (the area under the water demand curve) was estimated for the baseline (current storage rule, no trade with NSW Murray), and for two trade scenarios. The first trade scenario assumes that the current entitlement system and associated storage rules are used. The second trade scenario examines the case where an efficient storage market is able to determine the spatial-temporal equilibrium. The change in economic surplus, relative to the baseline, is shown for two trade scenarios in Table 1. Using the current storage regime, there is an expected annual loss in value of \$5.32 million in the Goulburn region, and a gain for the importing NSW region of \$5.04 million. The net effect of introducing trade is slightly negative. In contrast, there are

[1] Available at URL http://www.murrayirrigation.com.au/watexch/.

Table 1 Change in expected value of water use and distributional impacts, following introduction of broader trade opportunities under two storage scenarios (difference from baseline)

	Current storage	Market based storage
Change in expected annual value of water use (from baseline) $m		
Water used in Goulburn	–5.32	–0.45
Water used by importing region	5.04	4.86
Net impact	–0.28	4.42
Distributional impacts (change in expected annual values from baseline $m)		
Goulburn		
Change in producer surplus	–5.32	–0.45
Change in revenue earned from trade	4.10	3.89
Change in total income	–1.22	3.45
Importing region		
Change in producer surplus	0.94	0.97

positive gains from trade when storage is based on market conditions – the change in the value of water use in the Goulburn region is minimal whilst the water is used to produce $4.86 million in the importing region.

The distributional impacts of these scenarios are also shown. Under the current water entitlement/storage system, the irrigators in the Goulburn valley are made worse off by the trading regime. Revenue earned from trade in periods when it is profitable to trade are worth $4.1 million on average, but these gains are undermined by a loss in reliability which leads to a loss in producer surplus of $5.32 million on average. The value of this loss in reliability is not enough to compensate the gain in income and the gain in producer surplus in the importing region. In contrast, when a market based storage rule is used, Goulburn irrigators are made better off through the introduction of trade with NSW. This is because the opportunity cost of storage is taken into account when making decisions about current period use and sale of water. Under the market based scheme both trading partners are better off.

Results presented in Table 1 demonstrate the mean annual effect, which can be put in perspective by comparing them to the mean annual value of rents earned on the temporary water market in the Goulburn of around $3 million in 'normal years' (Brennan 2007) and the mean annual rental value of water entitlements simulated in the baseline model run of $67 million. Thus it can be said that the loss in the economic value of water use in the Goulburn is of a larger magnitude than the economic rents currently generated on the existing spatial market, and is equivalent to around 8 per cent of the rental value on current water entitlements. However, the net loss in income for farmers in the region is only 2 per cent of the value of water entitlements after the revenue from exports is accounted for.

The reporting of mean annual effects masks the impact of the trading regimes on water reliability. Increased frequency of seasons with low water availability will not only lead to hardship for the farmers but for tax payers

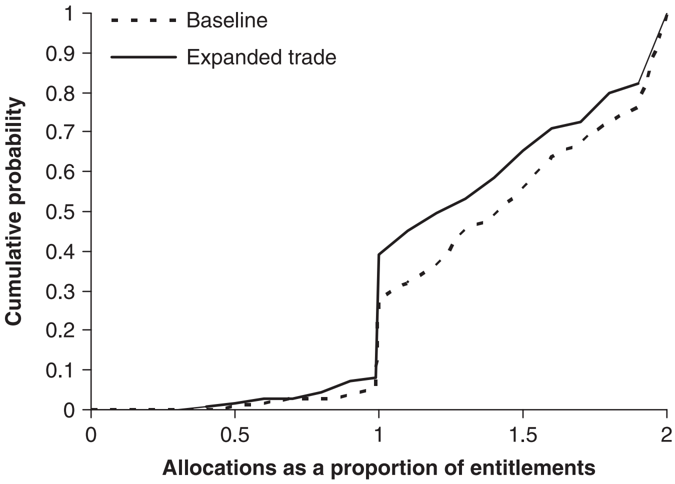

Figure 7 Impact of trade on the reliability of entitlements under existing storage regime.

as well, given tendency of Australian governments for making drought relief payments. The following figures demonstrate the impact of the alternative trading regimes on reliability. First, the reliability of the current water entitlement (as measured by allocations announced as a proportion of water entitlement) is shown in Figure 7. The introduction of trading shifts the reliability curve to the left, implying a greater probability of low water allocations. This is the result of a reduction in 'residual storage'. The probability that full entitlements will not be received is doubled, and there is a lower chance of receiving higher allocations.

The impact of the trading regimes on water use in the irrigation season is shown in Figure 8. In the case of the 'current storage' regimes, the patterns of use differ from the simulated patterns of entitlement reliability shown in Figure 7, because they include the modelled uptake of allocations. Compared to the baseline, the expanded trade scenario with the current storage regime leads to a greater likelihood of high water use, reflecting greater uptake of allocations via trade, which in turn undermines reliability. The 'optimal' storage scenario shows a lower tendency toward higher utilisation but also an increased tendency for low utilisation. The reason for this is that in periods of relatively high rainfall when water values are low, it is optimal to put relatively more water into storage in those years. That is, low water use in the 'optimal case' is generally a matter of choice, rather than a 'scarcity induced' low level of use.

That low water use coincides with low opportunity cost in the 'optimal storage' case can be further demonstrated by examining the probability of high prices simulated from the model runs, as shown in Table 2. Under the baseline scenario, market prices exceeded \$120 per mL in 17 years out of 113 in the simulation; and exceeded \$150 per mL in six years and twice exceeded

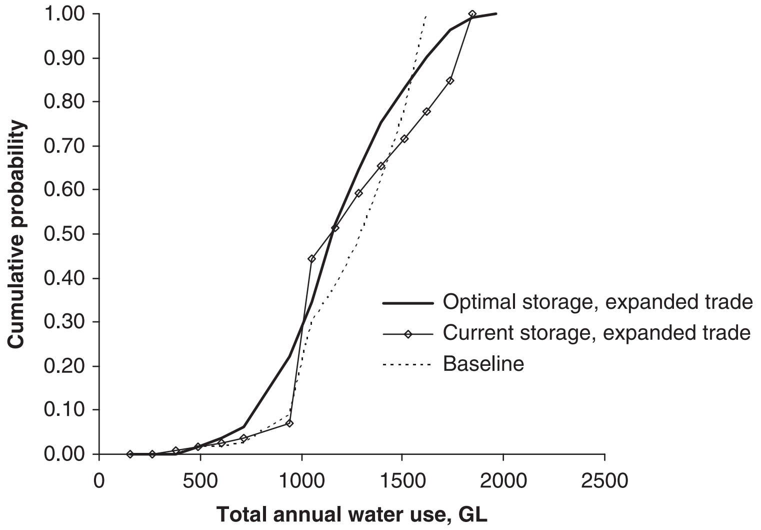

Figure 8 Impact of trade on the probability distribution of current season use, baseline and expanded trade with current and optimal storage.

Table 2 Impact of trade on mean water prices and the frequency of very high prices

		With expanded trade	
	Baseline	Current storage	Market based storage
Mean price (per mL)	$67.2	$79.6	$68.9
Number of times price exceeds			
$120/mL	17	25	7
$150/mL	6	12	4
$250/mL	2	2	1

$250 per mL. With expanded trade and using the same storage policy, the frequency of high prices increased to 25 ($120 per mL) and 12 years ($150 per mL). In contrast, the introduction of a storage market at the same time as broadening trade actually reduces the likelihood of very high prices. Only in the drought of 1914, which was a year of extremely low irrigation season rainfall and low winter inflows, did the simulated price exceed $250 mL in the 'optimal storage' case, just as it did under the 'current regime' storage rules.

5. Conclusions

This analysis demonstrates the problems associated with expanding spatial trade when rights to storage are not properly defined. Existing entitlement holders are currently beneficiaries of 'residual storage' which underwrites the reliability of entitlements. The introduction of broader spatial trade creates greater opportunity for current season use. In contrast, the introduction of clearly defined property rights to storage would allow for the development of a storage market which would then allow for the gains from trade – in both spatial and temporal dimensions – to be achieved.

The extent of the market failure problem was shown to be a significant economic problem when compared to the value of rents normally generated on the spatial market in the Goulburn Valley. The analysis conducted here probably underestimates the true value associated with introducing trade when storage rights are not properly defined, because the reliability of rights in the Goulburn system were probably already undermined through the introduction of inter-valley trade in Victoria. The water policy reforms recently introduced in the lower Murray, which allow for expanded spatial trade of ‘tagged’ permanent water entitlements may not deliver the perceived benefits, at least from the perspective of Victorian irrigators who have high value sunk irrigation investments.

Finally, a comment on the December 2007 policy decision (Government of Victoria 2007) to grant rights to carryover Victorian irrigators is necessary. In theory, the granting of rights to carryover will reduce the magnitude of the missing markets problem demonstrated in this analysis. However, the carryover policies that exist in the lower Murray at the present time do not represent the ‘competitive storage’ scenario presented in this study because rights to carryover are attenuated. For example, the Victorian policy states that irrigators lose their rights to their stored water if allocations are above 70 per cent. In the case of New South Wales, irrigators had rights to carryover relinquished in the drought of 2006–2007. The economic impact of the attenuation of carryover rights is an area that requires further research.

References

Beare, S. and Heaney, A. (2002). *Water Trade and the Externalities of Water Use in Australia*, ABARE report prepared for the Natural Resource Management Unit, Department of Agriculture, Fisheries and Forestry, Canberra, ACT.

Brennan, D. (2006). Water policy reform in Australia, lessons from the Victorian seasonal water market, *Australian Journal of Agricultural and Resource Economics* 50, 403–424.

Brennan, D. (2007). Managing water resource reliability through water storage markets, Working paper, available from the author.

Brennan, D. and Scoccimarro, M. (1999). Issues in defining property rights to improve Australian water markets, *Australian Journal of Agricultural and Resource Economics* 43, 69–89.

Goesch, T. and Beare, S. (2004). Water rights and trade: meeting the water reform agenda, *Australian Commodities* 11, 180–189.

Government of Victoria (2007). Holding: Carryover here to stay. Minister for Water Media Release, 4th December 2007. Available at URL <http://www.dpc.vic.gov.au/domino/Web_Notes/newmedia.nsf/b0222c68d27626e2ca256c8c001a3d2d/29e69b08c47e22cdca2573a7007b7821!OpenDocument> [accessed 3 September 2008].

Heaney, A., Dwyer, G., Beare, S., Peterson, D. and Pechey, L. (2006). Third-party effects of water trading and potential policy responses, *Australian Journal of Agricultural and Resource Economics* 50, 277–294.

James, B., Erlanger, P.D. and Hansen, W.R. (1993). Modelling a Complex Irrigation Restriction Policy Using a General Simulation Package Hydrology and Water Resources Symposium, Newcastle, June 30–July 2 1993.

Marsden, J. (2002). Water entitlements and property rights: an economic perspective, Chapter 3 (p. 43–54), in Property: Rights and responsibilities, Current Australian Thinking, Land and Water Australia, available from URL: http://www.lwa.gov.au/downloads/publications pdf7PR020440.pdf [accessed 30 January 2007].

Williams, J.C. and Wright, B.D. (1991). *Storage and Commodity Markets*. Cambridge University Press, Cambridge.

Young, M. and McColl, J. (2003). Robust Reform: The case for a new water entitlement system for Australia, *The Australian Economic Review* 36, 225–234.