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Price elasticity of water allocations demand in the Goulburn–Murray Irrigation District*

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Bid prices for the demand and supply of water allocations between 2001 and 2007, and average monthly prices paid for water allocations from 1997 to 2007 in the Goulburn–Murray Irrigation District are analysed to estimate price elasticities. Based on bid prices, the price elasticity of demand for water allocations appears highly elastic, with elasticities strongly influenced by the season and drought. The price elasticity of supply for water allocations is also elastic, albeit less elastic than demand. Using actual prices paid, water demand is negatively related to price and is inelastic, and appears to be most influenced by demand the previous month, drought and seasonality factors.

Key words: water allocations demand, water allocations supply, price elasticity, water markets.

1. Introduction

In an era of fixed supply and general scarcity, the use of economic instruments to manage demand for water has increasingly been promoted by international organisations such as the UN, the World Bank and the OECD. Since 1994 Australia has promoted markets as an integral part of agricultural water management. Compared to most other countries, markets in water allocations (also known as temporary water markets, these involve the right to short-term use of water) have developed to a high level of maturity. By contrast, markets for water entitlements (also known as permanent water markets, these involve the long-term right to access water), as in other countries, have been more subdued as irrigators perceive water entitlements as an inherent part of the farm (Tisdell and Ward 2003). Farmers can buy and sell water on a temporary basis, or on a permanent basis, depending on their perceived needs. Prices in the two markets have increased considerably over time and the two prices are closely linked, following the same cyclical pattern but with allocation prices fluctuating more than twice as much as entitlement prices (Bjornlund and Rossini 2007).

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Understanding irrigators' responsiveness to changes in water prices is an essential element when evaluating the effectiveness of using water markets as a policy instrument. Despite agricultural water markets being in existence for some 20 years in Australia, there have been relatively few attempts to estimate the price elasticity of traded water allocations or entitlements or to identify the factors impacting on volumes traded in such markets. This is mainly because of a paucity of water pricing data, 'thin' markets in many areas and the private nature of price information. To overcome these obstacles this paper combines publicly available price and quantity data from the Goulburn–Murray Irrigation District (GMID) in Northern Victoria, with information from the major water broker in the region. The result is a consistent time-series of prices and volumes traded in the market for agricultural water allocations in Australia's largest irrigation district.

2. The study region and water trading background

The GMID is located in Northern Victoria along the River Murray. Irrigation within the district is mainly supplied by two major sources: the Goulburn and the Murray Rivers. Initially, trade in this region, in both the markets for water allocations and entitlements, was low (Tural *et al*. 2005).

By July 2004, fewer than one in five farm businesses within the GMID had never traded any type of water, and in many areas the figure was below one in 10. During the very dry seasons of 2002–03 and 2003–04, 60 per cent of all farm businesses were active in buying or selling allocations or entitlements (Bjornlund 2006). Water purchased in the allocation market, as a percentage of total water use within the GMID, has increased from about three per cent during periods of high supply in the mid-1990s, to almost a quarter in 2002–03 (Table 1). These are clear signs of increased market adoption among water

Table 1 Volume traded as percentage of water use – the Goulburn and Murray Systems

	Goulburn System		Murray System	
Season	Allocation (%)*	% of trade†	Allocation (%)*	% of trade†
1995–96	150	7	200	3
1996–97	200	4	200	3
1997–98	120	9	130	13
1998–99	100	13	200	5
1999–2000	100	14	200	8
2000–01	100	16	200	2
2001–02	100	18	200	5
2002–03	57	24	129	16
2003–04	100	16	100	18
2004–05	100	18	100	22
2005–06	100	22	144	14
2006–07	29	37	95	20

*Maximum seasonal allocation; †total water trade for season as percentage of total water use.
Source: Based on Goulburn–Murray Water's Records.

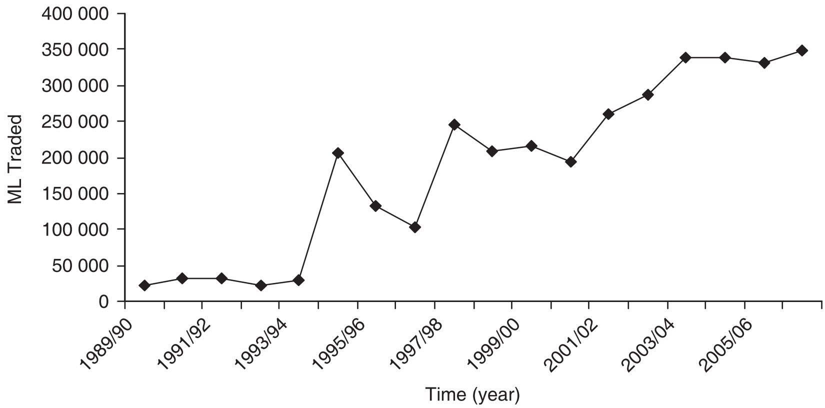

Figure 1 Volume traded in the allocation market in the GMID from 1989–90 to 2006–07. *Source*: Based on the records of Goulburn–Murray Water.

users. Dairy, fruit and grape producers are the most significant buyers in the water allocations market, whereas cereal, grazing and mixed farmers are the main sellers (Bjornlund and Rossini 2005, 2007).

At the beginning of each growing season (August), the local water authority announces an initial opening allocation of water – an amount each irrigator has by way of entitlement ownership. The initial allocation is a percentage of an irrigator's full entitlement, and is based on water availability in the storages. Allocations are progressively revised during the season as, or if, more water becomes available until final allocations are known, normally by February. In most years, irrigators within the Goulburn System have received their full allocation (Table 1), with the exception of the severe drought years of 2002–03 and 2006–07. In the recent drought year of 2006–07, opening allocations were 0 per cent and by December had increased to 24 per cent, with a closing allocation of 29 per cent within the Goulburn System. To use water beyond their allocation, irrigators can purchase water allocations from other irrigators. In general, the volume of water traded has been increasing over time (see Figure 1).

In 1998, after increasing demands for a faster approval process, Goulburn–Murray Water, the authority administering the GMID introduced a weekly water exchange. This allowed traders to bid for water on a Monday and get access to use the water on the Friday of the same week (Bjornlund 2003). In 2003, the exchange was extended to cover all of Victoria and the Murray Region of New South Wales. These multiple exchanges were gathered under the umbrella of WaterMove (www.watermove.au). Brennan (2006) provides more information on the Victorian water market and its operations.

WaterMove conducts water exchanges within a number of specified trading zones. Of the many regions covered by WaterMove, this study concentrates on the largest and most active zone; the Greater Goulburn trading zone within the Northern Victoria Regulated region. The exchange facilitates transactions in a number of 'products' including: Temporary Water Rights/

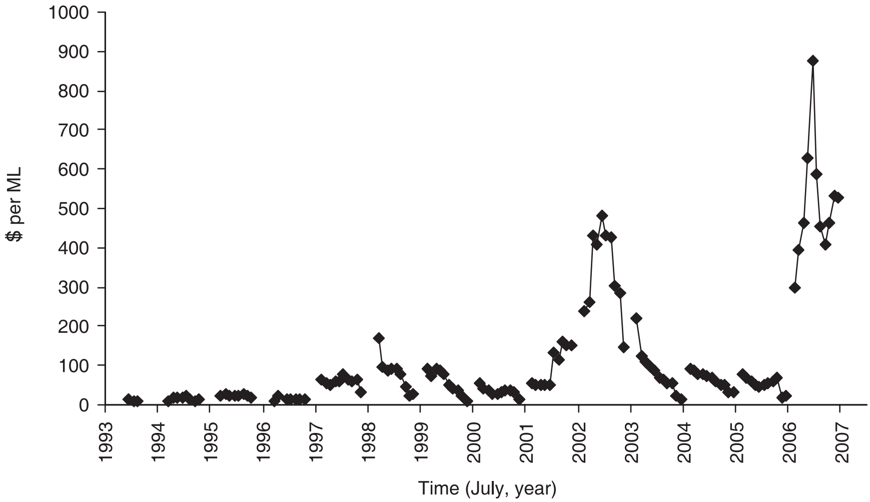

Figure 2 Monthly average pool prices paid for water allocations in the Greater Goulburn from 1993–94 to 2006–07.
Source: PlanRight, Tatura 1993–98, Water Exchange 1998–2007.

Diversion Licenses (here called water allocations), Temporary Sales, Permanent Used Water Rights/Diversion Licenses and Permanent Unused Water Rights/ Diversion Licenses. Trading typically occurs 10 months in every year (except June and July, the wettest months). The exchange operates as follows: buyers and sellers submit their bids to buy (sell) on a weekly basis. The bids must include the amount that they are prepared to buy (sell) and the price at which they are willing to buy (sell) the water. The exchanges are held every Thursday and the rules stipulate that the buyers be stacked in descending price order with the highest bidder eligible to buy first. The sellers are stacked in ascending order, with the lowest bidder eligible to sell first. The pool price is set at the level where the maximum volume is traded while no buyer pays more than their bid and no seller receives less than their bid. The pool price is the same for all successful buyers and sellers with some buyers paying less and some sellers receiving more than their bids.

This study analysed trade in the Temporary Water rights/Diversion License market, because it is the most active market. Yearly data on the volumes of water allocations traded is available from 1989 to 1990 (Figure 1), and monthly average prices paid for water allocations are available from July 1993 (Figure 2).

The annual volume of water traded has increased from less than 50 000 ML in 1989 to almost 350 000 ML by 2007, a seven-fold increase. While the quantity of water traded has steadily increased, prices have been much more variable, influenced by seasonal conditions such as the drought in 2002–03. Prior to 2001–02, average monthly prices ranged from $10/ML to $100/ML (except for one month where it reached $170/ML). Prices increased to $480/ ML in 2002–03, and fell again during the seasons of 2003–04 to 2005–06 before skyrocketing in 2006–07. Large variations are also reflected in the weekly pool price and quantity traded. For example, in 2002–03, the weekly pool price varied between \$500/ML and \$105/ML; the maximum quantity traded in a week was over 2500 ML and the minimum under 200 ML. In contrast, in 2004–05 the weekly price ranged between \$103/ML and \$26/ML while the quantity traded each week ranged from over 4000 ML to only 10 ML. During the drought season of 2006–07 prices reached \$950/ML by December while the accumulated volume traded at that time exceeded any other year and the volume traded in one single exchange was over 13 800 ML.

As a consequence of WaterMove's transaction procedures, consumer surplus (i.e. represented by the proxy of the difference between what the buyer bids for water and what they actually pay for it) is highest for the buyer who bids the highest price and then only pays the 'pool' price. This implies that a 'demand' curve for water constructed from the offer bids may contain spurious bids because of strategic behaviour from buyers to ensure a position on the top of the demand schedule. Such bidders are likely to know that the 'pool price' that they pay will be lower than their bid price, and that their bidding strategy will have little or no impact on the final pool price. Nevertheless, this study uses all the weekly supply and demand bids to construct bid curves for the six years from 2001–02 to 2006–07 in order to calculate price elasticities of water allocations.

2.1 Price elasticity literature review

The elasticity of demand for a product is defined as the percentage change in demand in response to a unit change in its price. Since, for a normal good, there is an inverse relationship between price and quantity demanded, the elasticity of demand is usually negative and the elasticity of supply is usually positive, as price goes up so should quantity supplied.

Elasticity estimates are sensitive to the method used to estimate them. In a recent paper, Scheierling *et al.* (2006) present a meta-analysis of 24 studies on irrigation water demand in the United States. Estimates are more elastic if they are derived from econometric studies or based on mathematical programming and less elastic if derived from models based on field experiments. Their work reveals a mean price elasticity of 0.48 and a median of 0.16 (in absolute terms), with larger elasticities in the longer run. They also reveal a large variation in the results, with elasticities ranging from 0.001 to 1.97. Overall, irrigation water demand elasticities seem slightly more elastic than residential water demand elasticities (i.e. Grafton and Kompas 2007 estimated a residential price elasticity of water demand for Sydney to be –0.35).

This variation in results highlights the difficulties of estimating water price elasticities. Additional to differences associated with the choice of estimation methods, Scheierling *et al.* highlight that: (i) studies differ in whether they assume that all other inputs (other than water) are held constant; (ii) water demand is more elastic at higher prices; (iii) studies vary in the range of prices and the time frame (and hence the opportunity for irrigators to alter behaviour) they study; (iv) the type of response that irrigators make to increasing prices (e.g. moving to higher value crops) in itself affects the value of additional water and the shape of their demand curve; (v) the mix of low, medium and high value crops covered in particular studies varies (different elasticities are associated with crop value); (vi) differences in climate impact on production functions; and (vii) the actual data used varies from study to study. In addition, we would highlight that not all water 'markets' are the same (with variation in the degree of regulation, utilisation, acceptance and efficiency of the market) and that many price elasticity studies are based on the price that water supply authorities charge to supply water (normally heavily subsidised) and not on prices paid in water markets.

Caswell and Zilberman (1985) and Caswell *et al*. (1990) showed increasing the water price impacted positively on the adoption of water conservation technology whereas Verela-Ortega *et al*. (1998) showed that such effects are related to the potential of diversification, water allocation and risk of water delivery. Others stipulate that an increase in water price may induce positive responses only in the range of prices where the demand is elastic (de Fraiture and Perry 2002) and that such price ranges often will be outside what is politically feasible (Perry 2001). For example, de Fraiture and Perry (2002) found that water demand is inelastic at low price ranges and became elastic only after a certain threshold price, suggesting that price increases in the order of 5–10 times were needed to induce water saving behaviour. They suggested that there is a gap between actual price and the productive value of water. Schoengold *et al*. (2006) found that water demand is more elastic than previously thought if considering the impact of higher marginal water prices on both the choice of crop or fallowing and on the choice of irrigation technology. Gomez-Limon and Riesgo (2004) found in Spain that within even homogeneous areas in terms of soil, climate and other factors, there are significant differences among farmers' reactions to price changes due to the variability in management criteria used to plan their crop mixes.

In Australia, given the limited number of market transactions and the lack of pricing information, most previous research has used mathematical programming models to derive price elasticities for water. This approach first estimates the value of the marginal product of water in an agricultural production system (Appels *et al*. 2004). It then estimates the optimal response of an individual to changes in the price of water under varying parameters, assuming they choose rationally. The literature also suggests, however, that irrigators' responses to pricing and other policy instruments are driven by many factors other than just financial considerations and are therefore not always economically rational (Gomez-Limon and Riesgo 2004; Kuehne and Bjornlund 2006). Consistent with the international findings, all estimates of Australian price elasticities based on mathematical programming have found the demand for irrigation water to be very inelastic at low prices. Short-run elasticity estimates range from –0.02 to –2.81, depending on the range of prices per megalitre (ML) (Pagan *et al.* 1997; Jayasuriya *et al.* 2001). For water prices below \$50/ML, demand was found to be relatively inelastic (Appels *et al.* 2004).

From an analysis of large-scale farm survey information for a variety of agricultural industries, Bell *et al.* (2007) report water demand elasticities from –0.8 to –1.9. Broadacre industries were more responsive to water prices than horticultural industries. On average, and holding other factors constant, Bell *et al.* (2007) found that a 1 per cent increase in the likelihood of farms trading water was associated with a 2 per cent increase in farms gross operating surplus.

The lack of information on individual's explicit demand for water has meant that previous estimates of elasticity have only considered average prices paid (de Fraiture and Perry 2002; Schoengold *et al.* 2006). In this study we use both information on whole bid curves for each exchange *and* average prices paid to calculate elasticities. The only other analyses that have been conducted on the entire demand and supply bid curves are Brooks and Harris (2005) and Zaman *et al.* (2004). Brooks and Harris (2005) estimated simple weekly demand and supply price elasticities for water allocations for the Greater Goulburn, Barmah-Nyah and Hume-Barmah zones from mid-2002 to March 2005. They estimated the average demand elasticity at 3.20, and the average supply elasticity at 3.50 for the Greater Goulburn trading area (both in absolute terms). Zaman *et al.* (2004) estimated weekly price elasticities in the Goulburn–Murray for 2002–03. Both of these studies produced a wide range of elasticity estimates, mostly because of thin trading in some weeks. Our study avoids this problem by using different model specifications and using data that cover a longer time period.

3. Results

3.1 Bid price elasticities of demand and supply

Water demand functions have traditionally used linear, log–log or log–linear functional forms, with the most popular being the log–log functional form (Schoengold *et al.* 2006). A variety of models were tested and the log–log functional form is presented here. Demand and supply price elasticities are calculated on six years of weekly allocation trading from July 2001 to June 2007 and are expressed as:

$$\begin{aligned}\ln \mathrm{DML}_t = \beta_0 + \beta_1 \ln \mathrm{DPrice}_t + \beta_2 \ln \mathrm{Alloc}_t + \beta_3\, \mathrm{Drought}_t \\ + \beta_4\, \mathrm{Year}_t + \beta_5\, \mathrm{Month}_t\end{aligned} \tag{1}$$

$$\begin{aligned}\ln \mathrm{SML}_t = \beta_0 + \beta_1 \ln \mathrm{SPrice}_t + \beta_2 \ln \mathrm{Alloc}_t + \beta_3\, \mathrm{Drought}_t \\ + \beta_4\, \mathrm{Year}_t + \beta_5\, \mathrm{Month}_t\end{aligned} \tag{2}$$

where t is the time period, DML is the water allocation volume demanded by buyers in ML for that week, SML is the volume offered by suppliers in that week, DPrice is the dollar amount offered per ML by buyers, SPrice is the dollar amount sought per ML by sellers. It is anticipated that there will be a negative relationship between prices and water demand, and a positive relationship between prices and water supplied. Alloc is the current allocation level of irrigation water in that week. It is hypothesised that farmers base their water demand and supply decisions on their current level of water allocation. Previous analyses of prices and volumes traded in the allocation market suggest that the main drivers of activities are low allocations and an increasing accumulated net deficit of water (i.e. Bjornlund 2003; Bjornlund and Rossini 2005; Brennan 2006). Drought is a dummy for the two severe drought years of 2002–03 and 2006–07, and it is hypothesised that during severe drought more water will be traded in the market as high value users (those whose crop values justifies purchasing water) will have to purchase a larger proportion of their total water need. Year is a continuous variable for the trading year in the database to detect if there is a time trend or some effect associated with a developing regional water market over time. Month is a series of dummies for the months in the trading year, to allow for seasonality factors. For example, some farmers delay buying water until they have used their seasonal allocation and find that their crop still needs water. They do this in the hope that that opening winter rains arrive early, or that prices will be lower later in the season, as has historically been the case in several seasons (Bjornlund 2003). Note too, that a variety of different seasonality variables were tested, such as month number, a quadratic factor for month and dummies for seasons, however, these variables had problems with collinearity. In another model specification price and month (plus price and month for each year) were interacted together to illustrate seasonality effects over the entire time period.

In this study, there are 17 713 observations in the demand model and 19 711 in the supply model; the entire set of available individual offers to buy and sell a given volume of water at a given price. Results for models one and two are displayed in Table 2 (with descriptive statistics and the results for other specifications in Tables A1 and A2 in Appendix I).

Table 2 illustrates that for the period from 2001–02 to 2006–07, the demand bid elasticity for water allocations is estimated to be –1.51, and the supply bid elasticity is estimated to be 0.89. Demand for water allocations is higher in drought years (while unsurprisingly the supply of water is less). When allocations of water increase, the demand for water falls, while over the years there has been a decrease in the amount of water demanded by bidders in the market – suggesting perhaps that outlandish demand bids have lessened in number as markets have become more developed or that buyers of water have become more efficient with their water use. On the other hand, there has been an increase in the supply of water by bidders in the market over time (shown by the Year variable). There is a definite seasonal pattern in the model, with water demand generally increasing each month from the start of the trading year (August) until demand becomes less in May and June. The supply of water on the other hand is higher at the start of the trading year, and falls throughout most of the year.

Table 2 Demand and Supply Bid Price Elasticities in the GMID for the period 2001–02 to 2006–07

Demand			Supply		
Variable	Coefficient	SE	Variable	Coefficient	SE
ln DPrice	−1.51	0.02***	ln SPrice	0.89	0.03***
ln Alloc	−1.71	0.06***	ln Alloc	–	–
Drought	0.88	0.06***	Drought	−2.30	0.05***
Year	−0.31	0.01***	Year	0.02	0.01***
Sep.	0.53	0.04***	Sep.	−1.06	0.10***
Oct.	0.96	0.05***	Oct.	−0.91	0.10***
Nov.	0.95	0.06***	Nov.	−0.75	0.10***
Dec.	0.83	0.06***	Dec.	−1.11	0.10***
Jan.	1.43	0.05***	Jan.	−0.62	0.10***
Feb.	0.96	0.06***	Feb.	−0.56	0.10***
March	1.18	0.06***	March	−0.29	0.10***
Apr.	0.92	0.06***	Apr.	−0.81	0.10***
May	−0.17	0.07**	May	−0.41	0.10***
June	−2.14	0.31***	June	−3.50	0.30***
Constant	21.63	0.27***	Constant	4.24	0.13***
n	17 713		n	19 711	
R^2	0.44		R^2	0.23	
F test	718.90***		F test	316.33***	

Notes: All models calculated with Huber–White heteroskedasticity-consistent standard errors and covariance and with bias correction best for heteroskedasticity. Due to collinearity problems, allocation could not be used in the supply model (Note: R^2 was still significantly lower than the R^2 for the Demand model when it was included).
***Significant at 1% level. **Significant at 5% level.

Figure 3 illustrates the monthly patterns of supply and demand elasticities in each year (obtained from the regressions reported in Table A2 in Appendix I) as well as the simple average demand and supply elasticity pattern across all six years. The monthly supply and demand elasticities were calculated by summing the coefficient of the price variable and the coefficient of the interaction term between time and price together. The resultant relatively stable seasonal pattern is consistent with the decision making pattern in the allocation water market identified through surveys (Bjornlund 2006). The price elasticity of monthly bid demand ranged from –1.71 to –4.14. As the lower panel shows, the average demand-bid price elasticity is in the elastic range through the entire season. It is lowest in the first trading month of the year while the market is dominated by more well-off and more conservative farmers buying what they need for the season. Demand bid elasticity remains relatively constant until March when it becomes more elastic, and it drops dramatically in June. From this point demand is normally only driven by irrigators' need to balance their water account for the season to avoid paying a penalty of $1000/ML for excess use.

The upper panel shows that the average supply offer price elasticity is also in the elastic range for the whole season (although some years do vary) and very

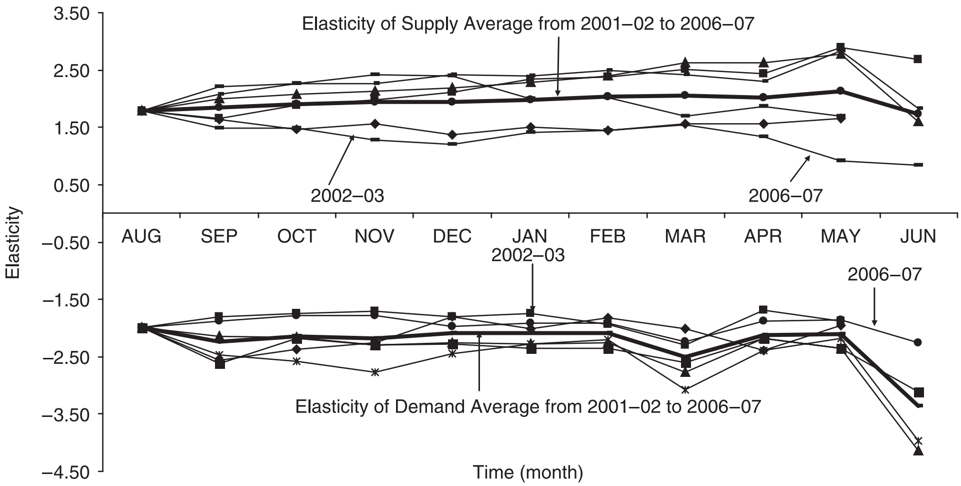

Figure 3 Monthly Demand and Supply Bid Price Elasticities in the market for Water Allocations in Greater Goulburn Region from 2001–02 to 2006–07.

gradually increases over the season until March, and becomes less elastic after May. The price elasticity of monthly supply for water allocations ranged from 0.84 to 2.84. Such an effect may be illustrating that in the beginning of the season the supply side is dominated by people who are selling all or a substantial part of their water each year (in effect their farming output is water) and which in turn depends on their early season cash-flow. Supply elasticity then slowly increases as low value active irrigators consider whether they will be better off selling their water or growing a crop. Elasticity reaches its highest points in summer when supply is provided either by speculative water sellers or by irrigators abandoning lower valued crops. The mean elasticity rises again in April to May as irrigators sell what they do not need in order to recover unavoidable supply costs. Thereafter the elasticity of supply falls.

In order to test whether the supply (or demand) bid price elasticities vary across time (e.g. the null hypothesis is either supply (demand) price elasticity is the same for every September from year 2001–02 to 2006–07 or supply (demand) price elasticity is the same for every month in a single year), we performed Chow tests and the results show that we can reject the null hypotheses at the one per cent significance level, hence elasticities were varying across time. The test results are not reported here due to space limit but are available upon request.

Water allocations demand-bid price elasticities are more elastic than water allocations supply bid price elasticities, both within season and across years (significant at the one per cent level). However, demand-bid elasticities fluctuate more significantly than supply bid elasticities within the season, but not across seasons. This may be because the demand side is dominated by active irrigators adjusting their trading activities during the season and from season to season in response to changing rainfall, evaporation, allocation levels and market conditions. On the other hand, supply offer elasticities fluctuate less so within the season as the supply side is dominated by farmers selling all their water each year and lower-value producing farmers who make the decision to sell their water early in the season. Such elasticities may fluctuate across seasons more given irrigators overriding need for water because of season conditions. Similar to demand-offer elasticities, supply-offer elasticities fluctuate the most early and late in the season (i.e. in the first three months and the last two months) as farmers decide whether to sell or irrigate and while water sellers try to read the market and find out when it will be most profitable to sell. One of the reasons elasticities fluctuate so much towards the end of the season is due to the small number of bid offers (which is reflected in the lack of significance of a couple of May and June interaction effects). Overall, our models explained the variance in demand for water allocations more so than the supply of water allocations. Such a result suggests that buying and selling water is quite a different activity for most farmers, and that more detailed individual level analysis (such as derived from farm surveys) is needed to suggest the real drivers of why farmers are selling water allocations.

The drought years of 2002–03 and 2006–07 produced monthly elasticity patterns different from other years. Demand and supply elasticities in drought years were much less elastic than in other years (as shown in Figure 3), and were both below the average yearly seasonal elasticity. Supply became inelastic in the last couple of trading months of 2006–07, reflecting the severity and the continuation of the drought. This is unlike the monthly demand and supply elasticities for 2002–03 which both regressed towards the average from April onwards (most likely because farmers knew that they would most likely be receiving their full allocation the following trading year given rainfall received). It is expected that both supply and demand elasticities will become more inelastic in the current year of 2007–08.

3.2 Average monthly price elasticities of water allocation demand

The previous two sections have considered price bid elasticities of demand and supply water allocations. It is important to note, however, that these are based on weekly individual offers and bids incorporating the entire range of values signalling willingness to pay and minimum acceptable prices – but not what traders actually paid and received. This section calculates price elasticities of demand for water for the longer period of 1997–98 to 2006–07 utilising average monthly prices paid for water allocations and, given increased monthly data availability, takes into consideration a wider range of possible influences on the demand for water. Prior to 1997 volumes traded are only available on an annual basis.

The demand for rural water is traditionally expressed as a function of price, income and other factors. The preferred model would express each farmer's demand for water as a function of a range of their farm and socio-economic characteristics over time, and future research should consider such an analysis. In this paper, however, given the limited available data, a region-level model is specified where the monthly total quantity of water allocations (WAVol) purchased by farmers in the GMID is the dependent variable. Apart from the independent variables used in our weekly bid elasticity models, other influences hypothesised to influence rural water demand were also included in the model: farm income, commodity prices, lagged demand, and a variable encompassing rainfall and evaporation factors.

$$\begin{aligned}\ln \text{WAVol}_t = \beta_0 &+ \beta_1 \ln \text{WAPrice}_t + \beta_2 \ln \text{WAVol}_{t-1} + \beta_3 \text{NDKyab}_t \\ &+ \beta_4 \ln \text{FarmGDP}_t + \beta_5 \text{Drought}_t + \beta_6 \text{Year}_t + \beta_7 \text{Month}_t \\ &+ \beta_8 \ln \text{MAlloc}_t + \beta_9 \text{CommodityPrices}_t\end{aligned} \tag{3}$$

The variables for drought, year and month are as defined in the first models (1) and (2). The first independent variable DATPrice_t is the average price for water allocations in the current month. The second independent variable WAVol_{t-1} represents lagged demand for water, as it is expected that the current month's demand is related to that from the previous month. Including such a term allows for the estimation of the long-run price elasticity (Hoffman *et al.* 2006). The third independent variable NDKyab_t is the net monthly water deficit in the region. This is calculated by subtracting monthly rainfall from monthly evaporation rates obtained form the Bureau of Meteorology for the Kyabram station. This variable is a proxy for the volume of water that the irrigators must apply additional to the needs of the plant. It is hypothesised that an increase in the net water deficit (i.e. more water is evaporating from the soil than is being replaced by rainfall), will lead to an increased demand for water. Brennan (2006) found a negative relationship between rainfall and prices, while Bjornlund and Rossini (2005) found a positive relationship between evaporation and prices in the Goulburn region's water allocation market. The fourth independent variable FarmGDP_t is the average monthly farm GDP as estimated by the Reserve Bank of Australia (RBA). It is hypothesised that farm GDP (which is a proxy for income of farmers) will be positively related to water demand. The eighth independent variable MAlloc_t is the current monthly allocation level of irrigation water. The remaining variables (PriceFB_t, PriceWh_t and PriceWo_t) are unit export commodity prices for feed barley, wheat and wool (provided by the Australian Bureau of Agricultural Resource Economics). (It should be noted too that a wide variety of agricultural prices were collected and tested – but none displayed any significance in the tested model.) Previous studies have found that water demand is positively related to commodity prices, although they appear to be less important than water scarcity (Bjornlund and Rossini 2005; Brennan 2006). Bjornlund and Rossini (2005) suggest that when prices on the allocation market increased to $500/ML in 2002–03 this was caused by horticultural farmers protecting their long-term investments in plantings, with dairy farmers protecting their

Table 3 Demand for Monthly Water Allocations (DML) in the GMID from 1997 to 2006 using OLS and 2SLS

	OLS		2SLS	
Variable	Coefficient	SE	Coefficient	SE
ln WAPrice	0.05	0.10	−0.52	0.27**
ln $WAVol_{t-1}$	0.35	0.09***	0.36	0.09***
NDKyab	0.00	0.00**	0.00	0.00
ln FarmGDP	1.13	0.78	1.45	0.73**
Drought	0.85	0.33***	1.40	0.51***
Year	0.05	0.03	0.03	0.03
Sep.	2.26	0.26***	2.30	0.23***
Oct.	1.56	0.27***	1.67	0.24***
Nov.	1.41	0.31***	1.60	0.27***
Dec.	1.57	0.38***	1.83	0.35***
Jan.	1.86	0.41***	2.15	0.38***
Feb.	2.03	0.34***	2.17	0.32***
Mar.	2.16	0.35***	2.27	0.33***
Apr.	2.03	0.30***	1.98	0.31***
May	1.49	0.28***	1.06	0.38***
June	0.31	0.32	−0.26	0.41
ln MAlloc	0.12	0.16	–	–
ln PriceFB	−1.14	0.70**	–	–
ln PriceWh	0.43	0.69	–	–
ln PriceWo	0.44	0.56	–	–
Constant	−4.39	7.18	−6.25	6.56
	n	101	*n*	101
	Adjusted R^2	0.82	Centered R^2	0.80
	F stat	23.54***	*F* stat	19.50***
			Sargan stat	0.854
			Durbin–Wu–Hausman χ^2	4.31**
			Wu–Hausman *F*	3.70*
			Pagan–Hall General stat	9.72

Notes: ***Significant at 1% level. **Significant at 5% level. *Significant at 10% level.

long-term investments in dairy herd and milking equipment at prices up to around $300/ML. Taking a long-term position, it is rational for farmers to pay more for water than appears profitable in the short-run. There is also anecdotal evidence of banks lending money to dairy farmers to purchase water at loss making prices to ensure their long-term ability to service debt.

Table A1 in Appendix I provides a summary of the descriptive statistics (in terms of means, maximums, standard deviations, skewness and kurtosis) for the average price monthly model from July 1997 to June 2007.

Table 3 presents the results of various specifications of the model with 101 monthly observations in each. In the original specification of the model (OLS), the price variable for temporary water was found to be endogenous. As a result, its coefficient was positive (albeit) insignificant. There were also problems with collinearity. The model was respecified with 2SLS, with ln PriceFB, ln PriceWh, ln PriceWo and ln Alloc acting as instrumental variables for ln $WAPrice_t$, and was calculated with robust standard errors. The selection of these instruments satisfies the criteria that they are correlated with ln $WAPrice_t$, and they are exogenous of the monthly water demand equation. Tests of over-identification and endogeneity were also undertaken, which showed that our model was appropriately specified and no longer suffered from endogeneity of ln WAPrice. With regard to the possible serial correlation of the error term in our model, the estimator we used accounted for the first order autocorrelation function of the error term. Stationarity of the dependent variable and regressors was thought not to be a concern in our final model given the model's 2SLS estimation, as pointed out by Hsiao (1997).

The analysis shows that average demand for water allocations is significantly and positively influenced by demand in the previous month, farm GDP, seasonality factors and drought.

The price of water allocations in the current month was negatively and significantly related to water demand. The short-run elasticity is calculated at the means, and the long-run elasticity is calculated from the lagged demand coefficient at the mean. The short-run price elasticity of water demand at the mean is –0.52 while the long-run price elasticity of demand at the mean is –0.81. This indicates that a 10 per cent increase in the price of water allocations decreases the demand for water allocations by 5.2 per cent in the short-run and 8.1 per cent in the long-run. Although the price of water does play a role in limiting its demand, other factors such as seasonality factors and drought would appear to be more important in influencing the average monthly demand for water allocations. During periods of drought irrigators' demand for water is high while supply in the form of seasonal allocations is low. High value irrigators are therefore willing to pay high prices to avoid losing their plantings or dairy herds and to stay in business and as a result water demand is inelastic overall.

4. Conclusion and policy recommendations

This paper has provided several estimates of the elasticity of demand and supply for water allocations for one region along the Murray River in Australia over the period 1997–2007. Based on traders' bids for water allocations on WaterMove, the price elasticities of bid demand by month ranged from –1.71 to –4.14, while the overall price elasticity of demand ranged from –1.51 to –1.99. The monthly price elasticities of supply for water allocations ranged from 0.84 to 2.84, while the overall price elasticity of supply ranged from 0.89 to 1.79. Our models explained the variance in demand for water allocations more so than the variance in supply of water. Elasticity varies over the trading season, which suggests that the elasticity of demand and supply for water is highly dependent upon the time of the season and market prices. It was also found that demand elasticity was highest and fluctuated the most within a given year, and that it became very elastic towards the end of the season. This suggests that active irrigators responding to fluctuating weather and market conditions are dominating the demand side. On the other hand water sellers and lower value producing irrigators deciding to sell all or a large proportion of their water early in the season and the high need for water because of drought conditions dominate the supply side.

Our more comprehensive model of water allocations demand (this time using actual water traded against actual prices paid) over the time period from 1997 to 2007, found that once price was corrected for endogeneity, demand elasticity was estimated to be between –0.52 in the short-run and –0.81 in the long-run, with seasonality factors and drought again playing the largest influence on water demand. It is clear from these results that elasticities vary considerably, with those calculated from bid estimates much more elastic than those from average monthly prices. Such a result is to be expected given the structure of Watermove's bids and the average monthly price paid for water allocations.

It is clear there is a need for more and better studies of water demand and supply elasticities. Current government policies that use markets to reallocate scare water resources depend on irrigators to respond to price signals. On the whole, it seems that average demand for water allocations in the GMID has been inelastic over the period from 1997 to 2007. Inelastic responses or responses that indicate that it will take decades to reallocate water volumes effectively signal the ineffectiveness of such policies. This in turn requires that governments have a clear target as to the aggregate amount of water they wish to see reallocated. Not only will this require better information about aggregate flows, such policies require a clear differentiation between (and measurement of) water consumption and water distribution elasticities. Our results suggest that the continuing pressure on water supply and allocations from the current drought may lead to a decrease in supply and demand water allocations elasticities across the region. Further research in this area will be needed.

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Appendix I

Table A1 Descriptive Statistics of variables used in regressions

Variable	Mean	SD	Minimum	Maximum
Demand Bid Price Weekly Model				
ln DML	7.56	1.37	–0.69	10.40
ln DPrice	4.86	0.88	2.20	7.31
ln Alloc	4.09	0.68	1.61	4.61
Aug.	0.06	0.24	0.00	1.00
Sep.	0.11	0.31	0.00	1.00
Oct.	0.10	0.30	0.00	1.00
Nov.	0.09	0.28	0.00	1.00
Dec.	0.06	0.24	0.00	1.00
Jan.	0.13	0.34	0.00	1.00
Feb.	0.11	0.32	0.00	1.00
Mar.	0.16	0.36	0.00	1.00
Apr.	0.14	0.35	0.00	1.00
May	0.05	0.22	0.00	1.00
Jun.	0.00	0.04	0.00	1.00
Year	3.19	1.86	1.00	6.00
Drought	0.42	0.49	0.00	1.00
Supply Bid Price Weekly Model				
ln SML	7.04	1.33	–0.36	9.82
ln SPrice	4.96	1.05	–0.69	7.31
ln Alloc	4.08	0.64	1.61	4.61
Aug.	0.03	0.16	0.00	1.00
Sep.	0.07	0.26	0.00	1.00
Oct.	0.09	0.28	0.00	1.00
Nov.	0.10	0.31	0.00	1.00
Dec.	0.08	0.27	0.00	1.00
Jan.	0.14	0.35	0.00	1.00
Feb.	0.13	0.34	0.00	1.00
Mar.	0.16	0.36	0.00	1.00
Apr.	0.13	0.33	0.00	1.00
May	0.07	0.26	0.00	1.00
June	0.00	0.04	0.00	1.00
Year	3.64	1.69	1.00	6.00
Drought	0.44	0.50	0.00	1.00
Monthly Average Price Model				
ln WAVol	9.81	1.03	6.68	11.42
NDKyab	106.99	88.21	–37.50	288.70
ln GDP_f	8.66	0.11	8.37	8.81
Year	5.65	2.89	1.00	10.00
Drought	0.20	0.41	0.00	1.00
ln WAPrice	4.43	0.97	2.38	6.77
ln MAlloc	4.29	0.60	1.61	4.79
ln PriceFB	5.26	0.28	4.81	5.87
ln PriceWh	5.47	0.13	5.25	5.82
ln PriceWo	6.62	0.20	6.18	7.07
Sep.	0.10	0.30	0.00	1.00
Oct.	0.10	0.30	0.00	1.00
Nov.	0.10	0.30	0.00	1.00
Dec.	0.10	0.30	0.00	1.00
Jan.	0.10	0.30	0.00	1.00
Feb.	0.10	0.30	0.00	1.00
Mar.	0.10	0.30	0.00	1.00
Apr.	0.10	0.30	0.00	1.00
May	0.10	0.30	0.00	1.00
June	0.04	0.19	0.00	1.00

Table A2 Demand and Supply Bid Price Seasonality Elasticities (with time and price interactions) in the GMID for the period 2001–02 to 2006–07

Demand Bid			Supply Bid		
Variable	Coefficient	SE	Variable	Coefficient	SE
ln DPrice	−1.99	0.04***	ln SPrice	1.79	0.05***
ln Alloc	−1.16	0.07***	ln Alloc	–	–
ln DPSepy1	−0.58	0.03***	ln SPSepy1	0.42	0.02***
ln DPSepy2	0.19	0.02***	ln SPSepy2	−0.16	0.02***
ln DPSepy3	−0.15	0.03***	ln SPSepy3	−0.13	0.01***
ln DPSepy4	−0.62	0.02***	ln SPSepy4	0.20	0.02***
ln DPSepy5	−0.47	0.04***	ln SPSepy5	0.29	0.03***
ln DPSepy6	0.12	0.01***	ln SPSepy6	−0.31	0.01***
ln DPOcty1	−0.41	0.03***	ln SPOcty1	0.48	0.03***
ln DPOcty2	0.31	0.02***	ln SPOcty2	−0.32	0.01***
ln DPOcty3	−0.20	0.03***	ln SPOcty3	0.1	0.02***
ln DPOcty4	−0.19	0.03***	ln SPOcty4	0.28	0.02***
ln DPOcty5	−0.40	0.04***	ln SPOcty5	0.48	0.02***
ln DPOcty6	0.11	0.01***	ln SPOcty6	−0.31	0.01***
ln DPNovy1	−0.39	0.03***	ln SPNovy1	0.62	0.02***
ln DPNovy2	0.24	0.02***	ln SPNovy2	−0.22	0.01***
ln DPNovy3	−0.18	0.03***	ln SPNovy3	0.19	0.02***
ln DPNovy4	−0.19	0.03***	ln SPNovy4	0.34	0.02***
ln DPNovy5	−0.60	0.04***	ln SPNovy5	0.47	0.03***
ln DPNovy6	0.21	0.01***	ln SPNovy6	−0.51	0.02***
ln DPDecy1	−0.27	0.03***	ln SPDecy1	0.61	0.03***
ln DPDecy2	0.28	0.02***	ln SPDecy2	−0.42	0.02***
ln DPDecy3	−0.30	0.03***	ln SPDecy3	0.33	0.02***
ln DPDecy4	−0.30	0.03***	ln SPDecy4	0.4	0.02***
ln DPDecy5	−0.78	0.04***	ln SPDecy5	0.62	0.02***
ln DPDecy6	0.20	0.02***	ln SPDecy6	−0.58	0.02***
ln DPJany1	0.19	0.03***	ln SPJany1	0.20	0.02***
ln DPJany2	0.19	0.02***	ln SPJany2	−0.28	0.01***
ln DPJany3	−0.27	0.03***	ln SPJany3	0.56	0.02***
ln DPJany4	−0.29	0.03***	ln SPJany4	0.49	0.02***
ln DPJany5	−0.45	0.03***	ln SPJany5	0.6	0.03***
ln DPJany6	0.01	0.02	ln SPJany6	−0.38	0.01***
ln DPFeby1	−0.03	0.03	ln SPFeby1	0.23	0.02***
ln DPFeby2	0.25	0.02***	ln SPFeby2	−0.35	0.02***
ln DPFeby3	−0.28	0.03***	ln SPFeby3	0.58	0.02***
ln DPFeby4	−0.36	0.03***	ln SPFeby4	0.61	0.02***
ln DPFeby5	−0.28	0.03***	ln SPFeby5	0.71	0.02***
ln DPFeby6	0.07	0.02***	ln SPFeby6	−0.34	0.02***
ln DPMary1	0.16	0.03***	ln SPMary1	−0.09	0.02***
ln DPMary2	0.06	0.02**	ln SPMary2	−0.23	0.01***
ln DPMary3	−0.26	0.03***	ln SPMary3	0.72	0.02***
ln DPMary4	−0.37	0.03***	ln SPMary4	0.84	0.02***
ln DPMary5	−0.22	0.03***	ln SPMary5	0.63	0.02***
ln DPMary6	0.07	0.02***	ln SPMary6	−0.25	0.01***
ln DPApry1	0.03	0.03	ln SPApry1	0.08	0.01***
ln DPApry2	0.11	0.02***	ln SPApry2	−0.23	0.01***
ln DPApry3	−0.36	0.03***	ln SPApry3	0.64	0.02***
ln DPApry4	−0.37	0.03***	ln SPApry4	0.83	0.03***
ln DPApry5	−0.20	0.03***	ln SPApry5	0.51	0.02***
ln DPApry6	0.13	0.02***	ln SPApry6	−0.46	0.01***
ln DPMayy1	−0.02	0.03	ln SPMayy1	−0.10	0.02***

Table A2 *Continued*

Demand Bid			Supply Bid		
Variable	Coefficient	SE	Variable	Coefficient	SE
ln DPMayy2	–0.30	0.03***	ln SPMayy2	–0.13	0.02***
ln DPMayy3	–0.79	0.04***	ln SPMayy3	1.10	0.03***
ln DPMayy4	–0.61	0.04***	ln SPMayy4	0.98	0.03***
ln DPMayy5	–1.08	0.06***	ln SPMayy5	1.05	0.03***
ln DPMayy6	–0.24	0.03***	ln SPMayy6	–0.88	0.02***
ln DPJuny3	–2.15	0.21***	ln SPJuny3	0.90	0.22***
ln DPJuny4	–1.13	0.05***	ln SPJuny4	–0.19	0.09**
ln DPJuny5	–1.97	0.86**	ln SPJuny5	0.04	0.31
ln DPJuny6	–0.26	0.05***	ln SPJuny6	–0.95	0.05***
Constant	22.11	0.36***	Constant	–2.16	0.25***
n	17 713		N	19 711	
R^2	0.62		R^2	0.56	
F test	303.42***		F test	302.54***	

Notes: All models calculated with Huber–White heteroskedasticity-consistent standard errors and covariance and with bias correction best for heteroskedasticity. Due to collinearity problems, allocation could not be used in the supply model, nor could months or years be included in either models.
***Significant at 1% level. **Significant at 5% level.