

Prices versus Rationing: Marshallian Surplus and Mandatory Water Restrictions*

R. QUENTIN GRAFTON and MICHAEL B. WARD

Crawford School of Economics and Government, the Australian National University, Canberra ACT, Australia

An aggregate daily water demand for Sydney is estimated and used to calculate the difference in Marshallian surplus between using the metered price of household water to regulate total consumption versus mandatory water restrictions for the period 2004/2005. The loss in Marshallian surplus from using mandatory water restrictions is calculated to be \$235 million. On a per capita basis this equates to approximately \$55 per person or about \$150 per household – a little less than half the average Sydney household water bill in 2005.

I Introduction

The ‘big dry’ that has affected much of South-East Australia since 2001 has reduced the water in storage in many locations. To help balance water supply and demand, State governments and water utilities have used mandatory water restrictions to reduce demand by banning various outdoor water uses. As of March 2008, at least 75 per cent of Australians live with mandatory water restrictions.¹ Surprisingly, until now, there has been no published

demand-based analysis that measures the welfare cost of mandatory water restrictions in Australian cities. We address this gap by measuring the loss in Marshallian surplus associated with mandatory water restrictions in Sydney over the period 2004/2005.² Our results show that raising the volumetric price of water charged to households to achieve the same level of consumption would generate a much higher Marshallian surplus than the use of mandatory water restrictions.

Section II reviews the existing studies from Australia and internationally that have tried to estimate the welfare losses associated with water rationing. Section III presents our estimates of an aggregate per capita daily water demand for Sydney. In Section IV we calculate the difference in Marshallian surplus from using a market-clearing price versus water restrictions, provide sensitivity analysis about the estimates, and give a brief discussion about the implications of the results. Section V offers concluding remarks.

* Presented at the 36th Australian Conference of Economists, Hobart 24 September 2007 and the 3rd Annual Water Pricing Conference, Sydney 27 September.

We are grateful for the helpful comments of two anonymous reviewers and for the invitation by Hugh Sibly to present our work at a special water session at the Australian Conference of Economists.

JEL classifications: Q25, Q58, D45

Correspondence: R. Quentin Grafton, Crawford School of Economics and Government, J.G. Crawford Building (13), Ellery Crescent, Canberra ACT 0200, Australia. Email: quentin.grafton@anu.edu.au

¹ Mandatory water restrictions have been in place, in one form or another, in Canberra since December 2002, in Sydney since October 2003, in Melbourne since November 2002, in Brisbane since May 2005, in Adelaide since 2002 and Perth since last century.

² In this century mandatory water restrictions in Sydney began on 1 October 2003 when Level 1 restrictions were imposed. Level 2 restrictions were implemented on 1 June 2004 and Level 3 restrictions have been in place since 1 June 2005.

II Background

(i) Prices versus Rationing

Rationing a scarce good equally among all consumers is not economically efficient if consumers are heterogeneous and have different marginal valuations for the good in question. Even if consumers are identical, rationing can still be inefficient if the good has different uses and at least one use is restricted such that marginal values differ across uses. Although water utilities and State governments are aware of the economic inefficiencies of rationing, they have frequently chosen to ration water in terms of when it is supplied, and how it is used, in times of low supplies.

The justification for rationing water versus charging a higher volumetric price is threefold. First, if water is considered a basic need then allocating it on the basis of price, especially if demand is price inelastic, may be inequitable because it can place a large cost burden on poorer and larger households. Second, in some communities, especially in poor countries, household water consumption is not metered. Thus, raising the water price in the form of a fixed charge provides no financial incentive to consumers to reduce their demand. Third, even when households are metered and are charged a volumetric price for their water the billing period is such (usually quarterly) that if an immediate and temporary reduction in demand is required, it may be more effective to implement a rationing scheme rather than raise the price.

These justifications for using water restrictions versus a higher volumetric price to reduce consumption are not valid, at least for most of metropolitan Australia in the twenty-first century. In terms of equity considerations, average water and waste water bills account for less than 1 per cent household income (Sydney Water, 2007; p.92). There also exists a well-developed welfare system in Australia to support disadvantaged households that could be supplemented with lump-sum rebates or other means (Grafton & Kompas, 2007) to offset increases in water prices. A free or low cost allocation of water could also be provided to all or only to disadvantaged households to meet basic needs—estimated by the World Health Organisation to be 50 L per day per person (Madden & Carmichael, 2007; p. 268).³

³ On average, per capita household water consumption in Australia is 285 L of water per day (Australian Water Association, 2007, p. 9).

Unlike many poor countries, most metropolitan households in Australia do have water meters, although Hobart is a notable exception. In multi-dwelling buildings occupiers are generally not individually metered, but frequently pay a *pro rata* water charge based on the area of their units.⁴ Despite these exceptions, higher volumetric prices would provide incentives to most Australian households to reduce water consumption. Finally, current water restrictions do not appear to be temporary phenomena in urban Australia. Indeed, millions of Australians have been subject to water restrictions in some form or another for several years with little prospect that this will change in the near future.

(ii) International Studies

Despite the potential welfare effects of household water restrictions there have been surprisingly few studies that have compared the use of volumetric prices versus water rationing. Only two studies have calculated the actual costs of water interruptions as a form of rationing – in Seville, Spain (Garcia-Valinas, 2006) and Hong Kong (Woo, 1994). Both studies found that the use of water interruptions is inefficient versus raising the price of water to households. Using Californian data Renwick and Green (2000) concluded that moderate reductions in demand (5–15 per cent) could be achieved through either modest price increases or public information campaigns, while large reductions require substantial price increases or mandatory water restrictions.

Mansur and Olmstead (2007) used daily household consumption data separated into indoor and outdoor use from 11 urban areas in Canada and the United States over a 2-week period in a dry, and also a wet season. They found that indoor consumption appears to be affected only by income and family size while outdoor use is price elastic during the wet season and price inelastic in the dry season. In their study, they separated households based on their household lot size and income level and found that households with the largest incomes and lot sizes have the least price elastic outdoor demand, while households with the lowest incomes and smallest lots are the most price elastic. They also found substantial gains from adopting price-based approaches to regulate water demand versus the use of outdoor water restrictions.

⁴ See Troy and Randolph (2006) for a useful discussion on differences in water consumption by household characteristics and attitudes to water consumption in Sydney.

(iii) *Australian Studies*

A number of studies have examined the issues of urban water pricing in Australia (Barrett, 2004; Sibly, 2006a), but only a handful have tried to estimate the welfare costs of water restrictions. Gordon *et al.* (2001) undertook a choice modelling survey with 294 Canberra residents in the late 1990s to compare alternative supply and demand responses to water scarcity. They found that, on average, respondents were prepared to pay \$150 to reduce water demand by 20 per cent through the use of voluntary measures and incentives for recycling rather than be faced with 20 per cent reduction in use from mandatory water restrictions. Hensher *et al.* (2006) also used a choice modelling approach in Canberra to calculate the marginal willingness to pay to avoid drought-induced restrictions. Their study was conducted in 2002 and 2003 and was based on 240 residential and 240 business respondents in Canberra. They found that residential respondents were unwilling to pay to avoid Stage 1 or 2 restrictions (Stage 1 = limit the use of sprinklers to morning or evening; Stage 2 = use sprinklers up to 3 h in morning or evening). They provided two possible explanations for this result. First, respondents may feel a 'warm glow' about using water responsibly that might offset their change in watering practices. Second, households might also be able to adapt relatively easily to Stages 1 and 2 water restrictions. Respondents, however, were willing to pay to avoid Stage 3 restrictions (use of sprinklers not permitted and hand held hoses and buckets only permitted in morning and evening), but only if the restriction lasted all year. Their point estimate for the marginal willingness to pay of respondents to shift from Stage 3 restrictions every day for a year to no restrictions was \$239.

Brennan *et al.* (2007) employed a household production function and experimental studies on lawns in Perth over three consecutive summers to calibrate a model of the time required to maintain a lawn. In their study, bans on the use of sprinklers can be substituted by household labour through the use of hand-held hoses or watering from buckets. Time spent watering by hand, however, reduces time for leisure activities that can be priced and, thus, the welfare costs of water restrictions can be calculated. They estimated that the per household welfare loss of a twice-per-week limit on the use of sprinklers costs about \$100 per summer, while a complete ban on sprinklers generates costs from \$347 to \$870.

Apart from our present study we are not aware of any published studies that calculate the welfare

costs of water restrictions for an entire community using actual water demands in Australia, or elsewhere. Using aggregate daily consumption for Sydney, the volumetric water price paid by households and rainfall and temperature data we estimate the price elasticity of demand. This estimated demand is used to calculate the difference in aggregate Marshallian surplus from the imposition of mandatory water restrictions that actually occurred to what it would have been had the volumetric price of water been raised to ensure the same level of consumption.

III Estimating an Aggregate Water Demand

Sibly (2006b) describes the potential welfare costs of using mandatory water restrictions instead of higher volumetric prices. These costs arise from an inability of households to equate the marginal cost of water to its marginal benefit in use. As a result, households who are willing to pay more for their water to satisfy particular uses, such as outdoor watering, are unable to do so, at least via the existing water distribution network. We provide estimates of this welfare loss by estimating an aggregate daily water demand for Sydney. Given that water, on average, represents a tiny fraction of household income the estimated demand (Marshallian) can be interpreted as a marginal value curve associated with water use and can be used to calculate differences in welfare.⁵

Using daily data on water consumption, maximum daily temperature, rainfall and an allowance for water restrictions we estimate a per capita aggregate water demand for Sydney. We hypothesise that demand is a function of real residential water prices, temperature (current and lagged), rainfall (current and lagged), and water restrictions. The chosen sample period used to estimate the water demand is from 1 January 1994 to 30 September 2005 which coincides with the period of a single-tier volumetric water price, which was uniform for all customers but which varied over time. Price, quantity, and restrictions data are from Sydney Water. Weather data are from the Bureau of Meteorology. To account for the water restrictions that occurred from November 1994 to October 1996, and introduced again in October 2003, we include two dummy variables as shift parameters. The difference in the demand estimates with and without

⁵ Household water expenditures (including sewerage charges) cost, respectively, the average household in Sydney, Melbourne and Brisbane \$747, \$537 and \$722 in 2005 (Australian Water Association, 2007; p. 10).

TABLE 1
Parameter Estimates of an Aggregate Per Capita Water Demand (Logarithm) in Sydney (1 January 1994 to 30 September 2005)

Variable	Coefficient	Standard error	<i>t</i> -statistic
Constant	-1.957	0.0041	-47.48
Real price (ln)	-0.173	0.027	-6.30
Maximum temperature (current period)	0.256	0.009	28.36
Maximum temperature (lagged period)	0.074	0.009	8.29
Rain (current period)	-0.001	0.0001	-8.64
Rain (lagged period)	-0.001	0.0001	-9.30
Dummy one (water restrictions in 1995)	-0.084	0.0103	-8.63
Dummy two (water restrictions since 1 October 2003)	-0.144	0.0123	-10.50

the most recent water restrictions provides the basic framework for the welfare analysis.

The results of the estimation are summarised in Table 1. Quantity, price, and temperature variables all entered the regression transformed into natural logarithm form. Rainfall and dummy variables entered the regression untransformed. All coefficients are statistically different from zero at the 1 per cent level significance. The estimated real price elasticity of -0.17 is less than that estimated by Grafton and Kompas (2007), but they use a smaller sample and do not include lagged (daily) values of temperature and rainfall. It is reasonable to expect that the price elasticity will be greater in the periods without water restrictions and we test for this difference. However, equality of the price elasticities estimates (with and without water restrictions) cannot be rejected and, thus, we use a single elasticity coefficient in the final and reported regression. The dummy variable imposed for water restrictions since 1 October 2003 indicates that the restrictions have resulted in about a 14 per cent decline in aggregate water consumption compared to what would have occurred without restrictions. The results also show that warmer weather and lower rainfall both increase the aggregate demand for water.

IV Marshallian Surplus: Prices versus Water Restrictions

The demand estimates in Table 1 can be used to assess the welfare costs of restrictions. We estimate these costs by picking a given 12-month period for which we have rainfall and temperature data, water restrictions and a single water tariff. The chosen period for the analysis is 1 June 2004 through 1 June 2005. Our estimates should be interpreted as indicative of the loss in Marshallian surplus from mandatory water restrictions rather

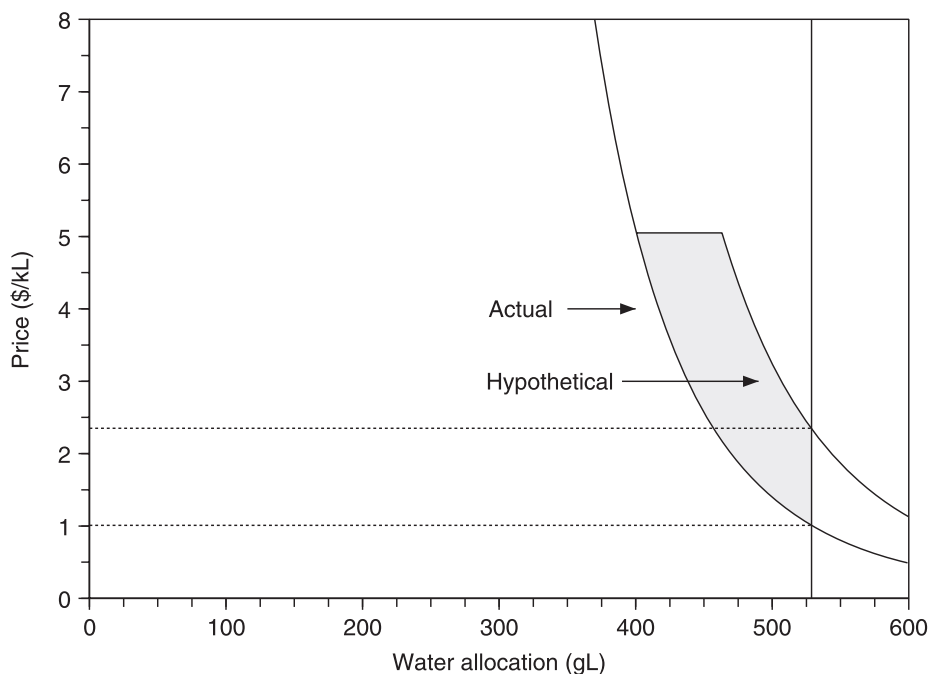
than a precise calculation of the loss for the chosen period. To calculate the annual demand we use the actual rainfall and temperature data for 2004/2005 period which we substitute into our estimated demand model and then multiply per capita quantity by population and sum over all observations.

The total water demand estimate is $q^T(p) = 6.12 \times 10^8 p^{-0.17}$ in kilolitres (kL) and calculated *without* the dummy for water restrictions imposed since 1 October 2003 such that it includes all types of water use (allowed and banned). The estimated demand for allowed uses, those not regulated by mandatory restrictions such as indoor use, is $q^A(p) = 5.30 \times 10^8 p^{-0.17}$ in kL. It is calculated with the dummy variable for water restrictions since 1 October 2003. The estimated demand for the banned uses or those uses prohibited under mandatory water restrictions is the difference between the two demands and is $q^B(p) = q^T(p) - q^A(p) = 8.28 \times 10^7 p^{-0.17}$ kL, at least for the observed price range.

Given there is a substitute for water supplied to households by Sydney Water – rain water tanks – there is some cut-off or choke price beyond which households are, in the long run, likely to switch to installing a rainwater tank. Using data and calculations that Marsden Jacob Associates (2007) undertook for the National Water Commission, we apply a choke price equal to \$5.05/kL when outdoor water use becomes zero.⁶ If the cost of

⁶ The \$5.05/kL price is based on the assumption households can use a roof of 50 square metres to catch the rain and install a 2 kL water tank (Marsden Jacob Associates 2007, p. 24). Alternative prices per kilolitre from a water tank can be calculated depending on the assumptions used about roof size, plumbing and pumping costs and the size of the tank.

FIGURE 1
Actual and Hypothetical Water Demand for Sydney 1 June 2004 to 1 June 2005



water provided by Sydney Water to households were higher than the average cost of water obtained from rainwater tanks then we assume that households would be able to substitute into water tanks to help meet their outdoor demand. Because it is a long-term adjustment and investment, some households with a marginal value of outdoor water above this cut-off price during the restriction period may not have installed rainwater tanks. Consequently our estimate of the welfare costs of water restrictions will understate the actual losses.

(i) *Reallocation in Water Uses*

Our welfare analysis takes total water consumption as fixed, and analyses the benefit of reallocation of water between allowed uses (indoor/washing) and banned uses (outdoor/landscaping). This net benefit can be approximated by the increase in Marshallian surplus from lifting restrictions while setting a price sufficient to keep total consumption unchanged. As shown in Figure 1, this net surplus is illustrated by the shaded area between the actual demand curve under mandatory restrictions and the demand curve that would exist under a

hypothetical removal of restrictions. Our study is a macro analysis and thus, we do not consider the micro or individual household issues associated with water conservation that are addressed elsewhere (Troy & Randolph, 2006).⁷

Our first step is to find the market-clearing price p^* which, absent restrictions, would induce demand to equal to what actually occurred with mandatory water restrictions. The actual volumetric price of water from 1 July 2004 was \$1.01/kL until a two-part tariff was introduced on 1 October 2005. The market-clearing price p^* can be approximated by $q^T(p^*) = q^A(1.01)$ which equals \$2.35/kL. This is illustrated in Figure 1 by the market-clearing price that ensures the hypothetical

⁷ Our demand estimates are based on total water usage, but some of this is lost in the system to leaks and seepage and non-household uses, for which we have no separate data. However, assuming non-household losses are constant and insensitive to price, correcting for these losses would simply shift both the actual and hypothetical demand curves to the left by this amount. The area between the demands, and thus, our estimates of Marshallian surplus, would be unchanged.

or counter-factual water demand generates the identical water consumption as the actual demand.

At the market-clearing price, consumers will reallocate some quantity of water from allowed to previously banned uses. This reallocation from lower-valued to higher-valued uses, on the margin, is the source of the welfare gain from removing restrictions. The consumer surplus loss from reducing allowed uses will be less than the consumer surplus gain from allowing the previously banned uses. To calculate the loss from reducing allowed uses, we integrate the inverse demand curve $p^A(q)$ between the quantity consumed at the actual price of \$1.01/kL and the predicted quantity at the market clearing price of \$2.35/kL. The loss in Marshallian surplus associated with this price change is calculated as follows:

$$\int_{q^A(1.01)}^{q^A(2.35)} p^A(q) dq = 1.12 \times 10^8 \quad (1)$$

To calculate the increases in consumer surplus from allowing previously banned uses we assume that the demand for banned uses is truncated to zero above the choke price of \$5.05/kL, which is the long run average cost of water from rain tanks. The Marshallian surplus associated with the reallocation can be calculated as the sum of two parts:

$$\int_{q^B(2.35)}^{q^B(5.05)} p^B(q) dq = 5.05q^B(5.05) + \int_{q^B(2.35)}^{q^B(5.05)} p^B(q) dq = 3.47 \times 10^8 \quad (2)$$

The difference between the estimated loss from eliminating water restrictions and using a market-clearing price estimated in Equation (1), and the estimated benefit from reallocation of water from indoor to outdoor uses in Equation (2), yields a positive Marshallian surplus of 2.35×10^8 or \$235 million. The extra revenue received by Sydney by using a price approach is not considered part of the welfare analysis as this could be returned to consumers via lump sum payments or lower fixed charges for water and possibly sewerage without losing the efficiency gains associated with a higher volumetric price.

Figure 2 illustrates the calculations described by Equations (1) and (2) in an equivalent way to that presented in Figure 1. The actual aggregate demand curve under mandatory water restrictions

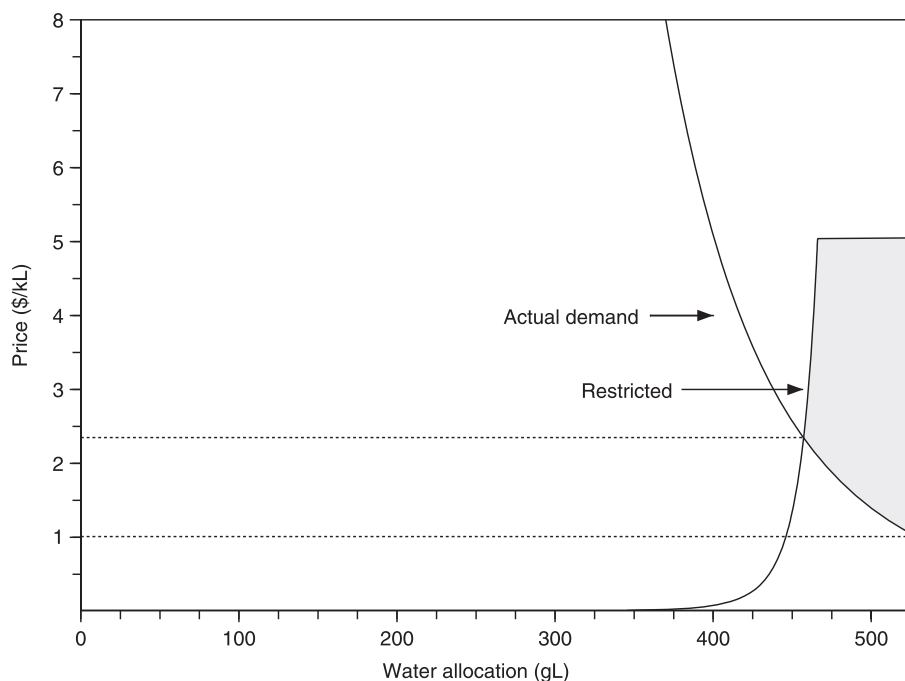
in Figure 2 is represented in the usual way, with the origin at 0 and consumption increasing from left to right. At the price of \$1.01 just over 520 gL of water is directed to allowed uses. The aggregate demand curve for banned uses (banned use = hypothetical – actual demand) is represented unconventionally with its origin at 520 gL at the far right of the horizontal axis that coincides with a volumetric price equal to the choke price for banned uses of \$5.05/kL. By contrast to the actual demand, the demand for banned uses increases from right to left along the horizontal axis. At the volumetric price of \$2.35/kL the increase in consumption of banned water uses exactly equals the reduction in consumption of allowed water uses from using a market-clearing price rather than mandatory water restrictions and a volumetric price of \$1.01/kL. The shaded area in Figure 2 represents the *net* consumer surplus of reallocating a fixed quantity of water from allowed uses to banned uses by using the market-clearing price $p^* = \$2.35/kL$ assuming that all the increased revenue from raising the price from \$1.01/kL is returned to consumers via lump-sum payments or lower fixed charges.

(ii) Welfare Costs of Water Tanks

To obtain a full measure of the costs of water restrictions we must also add the extra costs of water tanks that consumers have bought to offset mandatory water restrictions. According to the Australian Bureau of Statistics (2007) a total of 30 100 rainwater tanks were installed in Sydney since 2001. While we do not have information on the type of water tanks installed per household, a common type is a 2 kL tank adjoined to a 50 m² roof. An estimate of the expected annual yield from such a tank is 40 kL per year (Marsden Jacob Associates, 2007) that generates a 'levelised cost' per kL of \$5.05 or an average cost of \$202 per year. Thus, the annual financial cost of all tanks is estimated to be $30\,100 \times 202 = \$6.2$ million. However, the tanks also produce an average $30\,100 \times 40$ kL = 1.2 million kL, or <0.3 per cent of annual demand. This small amount of water could have been provided at the market-clearing price of water if they had been no water restrictions at a cost of \$2.8 million per year.⁸ Thus, the welfare loss from rainwater tanks is about \$3.4 million if

⁸ If a more substantial amount of water were provided by water tanks we would need to recalculate the market-clearing price that would generate the same level of water consumption as Level 2 mandatory water restrictions.

FIGURE 2
Actual and Banned (Hypothetical Less Actual) Water Demand for Sydney 1 June 2004 to 1 June 2005



they were purchased to overcome water restrictions. Adding this avoidable annualised net loss of \$3.4 million to the \$235 million gain in Marshallian surplus from charging $p^* = \$2.35/\text{kL}$, we derive a total benefit from prices versus rationing equal to \$238 million.

(iii) *Sensitivity Analysis*

Our estimates are based on statistical data and thus are subject to errors. Given that our welfare measures are nonlinear combinations of the estimated coefficients, the standard errors are difficult to compute directly. Thus, we construct our confidence interval for the estimated Marshallian surplus by using the method of Krinsky and Robb (1986) who used simulations to generate intervals associated with a Wald statistic. Using this approach, the 95 per cent confidence interval for the point estimate of the net gain in Marshallian surplus from using the market-clearing price is between \$196 million and \$252 million.

Our estimates of the Marshallian surplus from using volumetric prices to reduce demand are sensitive to both the choke price we use and the estimated price elasticity. Table 2 provides estimates

TABLE 2
The Market Clearing Price (\$/kL) with Different Choke Prices and Price Elasticities

Elasticity	Choke price (\$/kL)				
	3	4	5	6	7
-0.5	1.10	1.10	1.10	1.10	1.10
-0.40	1.22	1.22	1.22	1.22	1.22
-0.30	1.44	1.44	1.44	1.44	1.44
-0.20	2.00	2.00	2.00	2.00	2.00
-0.10	3.00	4.00	5.00	5.39	5.39

of the market-clearing price, p^* for different choke prices (\$/kL) and price elasticities. Table 3 provides a comparison of the Marshallian surplus for different choke prices and price elasticities. Although there is a large range in the welfare costs of water restrictions depending on the chosen values, in all cases the costs are substantial with a minimum value of about \$36 million and a maximum value of \$362 million.

TABLE 3
*Net Gain in Marshallian Surplus (\$ Millions) from Using
 a Market Clearing Price versus Water Restrictions with
 Different Choke Prices and Price Elasticities*

Elasticity	Choke price (\$/kL)				
	3	4	5	6	7
-0.5	35.8	49.8	62.2	73.6	84.2
-0.40	61.5	87.7	111.4	133.4	154.0
-0.30	87.1	128.9	167.6	204.2	239.0
-0.20	103.5	165.0	223.6	279.8	334.3
-0.10	64.0	126.4	199.7	281.0	362.2

Notes: The Marshallian surplus does not include the annual cost associated with the use of water tanks.

(iv) Discussion

Our findings concur with those of Hensher *et al.* (2006) and Brennan *et al.* (2007) that the welfare costs of permanent and high-level mandatory water restrictions can be very large. Indeed, our analysis of the welfare costs are likely to be a lower bound of the costs of water restrictions as we do not account for non-household losses such as those associated with bans on the use of public ovals.⁹ Notwithstanding the possibility of accessing increasing supplies from rural areas (Quiggin, 2006), desalination or recycling it would seem that water utilities, State and local governments would be well advised to consider alternative approaches to balance supply and demand to cope with low water supplies. In particular, they should use higher volumetric prices coupled with lower fixed charges (both water charges and sewerage charges) to balance supply and demand.¹⁰

V Concluding Remarks

Urban water utilities and State and local governments have employed mandatory water restrictions to help balance demand with dwindling supplies in response to a low rain fall period over

⁹ Our method accounts for households' disutility of time for banned water uses (such as watering the garden by a bucket) given a zero income elasticity and weak-complementarity between household labour and banned water use.

¹⁰ In 2004/2005 in Sydney, fixed water charges per household were \$77.62 and fixed sewerage charges per household were \$346.66. Thus, the rebates proposed from using a market-clearing price would lower the overall water and sewerage fixed charges but they would still remain positive.

the past six years or so in South-East Australia. As of March 2008, these restrictions are in force in all major urban centres in mainland Australia with the exception of Darwin. Indeed, in some locations mandatory water restrictions have been in place for several years and are becoming a permanent feature of urban life. Such an approach to managing water demand is not economically efficient and can impose substantial welfare losses. This is because households who are willing to pay more for water to satisfy particular uses, such as outdoor watering, are unable to do so through the existing water supply network.

Using daily water consumption data, real volumetric water prices and daily maximum water temperatures and daily rainfall data we are able to calculate an aggregate per capita water demand for Sydney for the period 1994–2005. The estimated demand is used to calculate the difference in Marshallian surplus between using the metered price of household water to regulate total consumption versus mandatory water restrictions for the period 2004/2005. Using the point estimate for the price elasticity of demand and a choke price of \$5.05/kL, we calculate the loss in Marshallian surplus from using mandatory water restrictions in Sydney to be about \$235 million over a 12-month period in 2004/2005. On a per capita basis this equates to approximately \$55 person or about \$150 per household – a little less than half the average Sydney household water bill in 2005.

Our findings suggest that mandatory water restrictions in urban Australia should be removed and the volumetric price of water increased to regulate water demand when required. To address equity concerns, the increase in revenue from higher prices could be returned to households in the form of lump sum payments through a lower, or even zero fixed charges. Such an approach to managing urban water demand offers the promise of large gains in welfare relative to the traditional approach of rationing water in periods of low rainfall.

REFERENCES

- Australian Bureau of Statistics (2007), *Households with Rain Water Tanks from 4602.0 by Capital City*. Australian Bureau of Statistics, Canberra.
- Australian Water Association (2007), *Water in Australia: Facts, Figures, Myths and Ideas*. Australian Water Association, Sydney.
- Barrett, G. (2004), 'Water Conservation: The Role of Price and Regulation in Residential Water Consumption', *Economic Papers*, **23**, 271–85.

- Brennan, D., Tapsuwan, S. and Ingram, G. (2007), 'The Welfare Costs of Urban Water Restrictions', *Australian Journal of Agricultural and Resource Economics*, **51**, 243–61.
- Garcia-Valinas, M. (2006), 'Analysing Rationing Policies: Droughts and its Effects on Urban Users' Welfare', *Applied Economics*, **38**, 955–65.
- Gordon, J., Chapman, R. and Blamey, R. (2001), 'Assessing the Options for the Canberra Water Supply: an Application of Choice Modelling', in Bennett, J. and Blamey, R. (eds), *The Choice Modelling Approach to Environmental Valuation*. Edward Elgar, Cheltenham, UK.
- Grafton, R.Q. and Kompas, T. (2007), 'Pricing Sydney Water', *Australian Journal of Agricultural and Resource Economics*, **51**, 227–41.
- Hensher, D., Shore, N. and Train, K. (2006), 'Water Supply Security and Willingness to Pay to Avoid Drought Restrictions', *Economic Record*, **81**, 56–66.
- Krinsky, I. and Robb, A.L. (1986), 'On Approximating the Statistical Properties of Elasticities', *Review of Economics and Statistics*, **68**, 715–9.
- Madden, C. and Carmichael, A. (2007), *Every Last Drop*. Random House Australia, Sydney.
- Mansur, E.T. and Olmstead, S.M. (2007), 'The Value of Scarce Water: Measuring the Inefficiency of Municipal Regulations', *NBER Working Paper 13513*. Available at <http://www.nber.org/papers/w13513>.
- Marsden Jacob Associates (2007), *The Cost Effectiveness of Rainwater Tanks in Urban Australia*. The National Water Commission, Canberra.
- Quiggin, J. (2006), 'Urban Water Supply in Australia', *Public Policy*, **1**, 14–22.
- Renwick, M.E. and Green, R.D. (2000), 'Do Residential Water Demand Side Management Policies Measure Up? An Analysis of Eight California Water Agencies', *Journal of Environmental Economics and Management*, **40**, 37–55.
- Sibly, H. (2006a), 'Urban Water Pricing', *Agenda*, **13**, 17–30.
- Sibly, H. (2006b), 'Efficient Urban Water Pricing', *Australian Economic Review*, **39**, 227–37.
- Sydney Water (2007), *Sydney Water Submission to IPART*. Sydney Water Corporation, Sydney.
- Troy, P. and Randolph, B. (2006), *Water Consumption and the Built Environment: a Social and Behavioural Analysis*. City Futures Research Centre, Research paper No. 5. University of New South Wales, Kensington, NSW.
- Woo, C. (1994), 'Managing Water Supply Shortage: Interruption versus Pricing', *Journal of Public Economics*, **54**, 145–60.