The Australian Journal of Agricultural and Resource Economics, 51, pp. 243–261

The welfare costs of urban outdoor water restrictions

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Outdoor water restrictions are usually implemented as bans on a particular type of watering technology (sprinklers), which allow households to substitute for labour-intensive (hand-held) watering. This paper presents a household production model approach to analysing the impact of sprinkler restrictions on consumer welfare and their efficacy as a demand management tool. Central to our empirical analysis is an experimentally derived production function which describes the relationship between irrigation and lawn quality. We demonstrate that for a typical consumer complete sprinkler bans may be little more effective than milder restrictions policies, but are substantially more costly to the household.

Key words: household model, urban water demand, urban water restrictions.

1. Introduction

Restricting the use of sprinklers for irrigating lawns and gardens is the most common drought management strategy used by urban water utilities in Australia. Backyard irrigation makes up at least half of all water consumed by the household sector in most Australian capital cities, and outdoor water restrictions create a significant opportunity for reducing demand during droughts, in a country that encounters greater climatic variability than any other continent (McMahon *et al.* 1992). Water utilities use stringent decision rules regarding the implementation of water restrictions, which include a quantitative measure of shortage (such as volume held in dams) that triggers implementation of water restrictions of varying severity. For example, Perth consumers have been restricted to using sprinklers only two days per week for the last five summers, consumers in Brisbane, Sydney, and in many regional centres were placed on complete sprinkler bans in the last one or two summers. Recent experience with a prolonged drought has meant that outdoor water restrictions of varying degrees of severity are currently impacting on more than 75 per cent of all households in Australia, and there is some concern that climate change will mean that restrictions become the norm in the future. In the case of Perth, where planning is now done on the

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doi: 10.1111/j.1467-8489.2007.00395.x

basis of recently dry climate rather than historic climate, there seems to be a policy consensus that it is better to have two day per week restrictions permanently in place than to run the risk of a less frequent but more severe sprinkler ban.

Aside from droughts, the dynamics of urban water demand and supply mean that outdoor water restrictions also offer flexibility to long-term investment decisions. Urban water utilities in growing cities face an increasing demand for water over time, which is generally met by lumpy supply augmentation opportunities such as building new dams, sourcing new underground supplies or constructing desalination plants. One option that the utility has is to use temporary rationing of available supplies in order to defer augmentation. The question of supply reliability – as measured by the risk of sprinkler bans – was considered explicitly in recent deliberations regarding augmentation options for the city of Canberra (ACTEW Corporation 2004). The economic regulator in Western Australia has questioned the timing of proposed augmentation of the urban water supply there, challenging the reliability targets set by the water utility which chose to build a desalination plant in order to keep the risk of complete sprinkler bans to 1 in 200 years (Economic Regulation Authority 2005).

Despite the importance of outdoor water demand in terms of total urban water use, and the role of restrictions in managing shortfalls in supply and in determining the timing of longer term supply decisions, there has been little attention paid by economists to the nature of the consumer problem. Yet the question of restricting outdoor water demand is a classic economic rationing problem, which could be approached through direct rationing measures including price policy and household level water allocations, or through indirect means that target water-using technologies, such as sprinkler bans or subsidies on water efficient appliances. One of the main problems associated with direct rationing is the difficulty in distinguishing between indoor and outdoor consumption drawn from a single metering point at the household level, and the high degree of heterogeneity in the size of the more inelastic indoor demand component. In contrast, the outdoor water restrictions via regulations on irrigation method (including time of day, days per week and sprinkler vs. hose vs. watering can) allows the more discretionary component of demand to be targeted and is therefore both easier to implement and considered to be more palatable to politicians.

One of the difficulties associated with analysing the welfare impacts of urban water restrictions is the lack of primary data to study the determinants of household water consumption and the effect of demand-side management policies on that consumption. A number of studies have used econometric analysis of panel data obtained by combining household water consumption data from water utilities, with household characteristics data derived from surveys or secondary data, in order to assess the efficacy of different types of drought management policies and their distributional implications (e.g. Renwick and Archibald 1998; Renwick and Green 2000; Schuck and Profit 2004; Garcia-Valinas 2006). Other studies have examined whether there is any evidence of a demand response to general conservation programs which may include policies such as advertising, retrofitting indoor appliances, as well as outdoor restrictions. (e.g. Nieswiadomy 1992). Recent work in Australia has used stated preference techniques to explicitly address the question of willingness to pay to avoid sprinkler restrictions. For example, using a choice modelling approach Gordon *et al.* (2001) found that consumers were willing to pay an extra $150 per year to have a more ‘voluntary based’ demand management approach (including incentive schemes for grey water recycling and efficiency regulations on new buildings) rather than mandatory restrictions aimed at achieving the same demand reduction. Hensher *et al.* (2006) found that households were willing to pay up to $239 extra on their water bills to move from complete sprinkler restrictions that apply every day and last all year to a situation where there are no restrictions at all. Whilst the results of these studies are useful for assessing optimal timing of supply augmentation because they allow the cost of sprinkler bans to be quantified, they do not allow investigation of the role of alternative demand management strategies on consumer welfare nor on the efficacy of the management tool.

Since restrictions on the use of sprinklers are an indirect means of rationing water use, they are likely to be inefficient and only partially effective as long as there are substitution options available. Most sprinkler-restrictions policies allow consumers to use a hand-held hose to water their lawns and gardens, and restrictions on sprinklers will invoke substitution for this more labour-intensive technology if the disutility from garden water-stress is large enough. Such substitution will affect the efficacy of the restriction policy in reducing overall water use and the welfare cost of the policy. The fact that Sydney and Brisbane utilities have had to revise sprinkler-restrictions policies to also ban the use of hand-held hoses provides support to the notion that labour substitution can occur when there are sprinkler restrictions in place. However, the relationship between effectiveness of a restrictions policy and its impact on consumer welfare is unknown. Yet this question is fundamental in determining the optimal timing, duration and severity of outdoor water restrictions policies which in turn impacts upon longer term investment in urban supply.

This paper seeks to provide an analysis of the trade-off between consumer welfare and efficacy of outdoor water restrictions by calibrating a household production model of the consumer choice to substitute between leisure and lawn quality. Household production models are typically used in labour market studies to understand time allocation (Aronsson *et al.* 2001; Kerkhofs and Kooreman 2003); or in agricultural development to study semi-subsistence production–consumption choices (e.g. Singh *et al.* 1992; de Janvry and Sadoulet 2001). The key feature of the approach is that it allows the incorporation of choices regarding the allocation of labour between production of ‘home-produced’ goods and leisure. In the present case the home-produced good is ‘lawn quality’ which is affected by sprinkler restrictions but the household can choose to substitute leisure for hand-watering and thus maintain quality. By adopting this approach we can directly incorporate available information regarding the ‘lawn quality production function’ to asses the efficacy of different water management policies, including pricing, sprinkler days, lawn variety and irrigation technology.

The outline of the paper is as follows. In the next section, a conceptual model of consumer preference for outdoor water use is presented using the ‘household production model’ approach, where demand for water is an input into the production of lawn quality, a consumer good. The calibration of the conceptual model is then presented, which includes a discussion of an empirical production relationship between water use and lawn quality, and other characteristics of the ‘cost function’ for lawn quality. The model is used to examine the response of a range of representative consumers (distinguished according to preference for greenness) to outdoor water restrictions of varying severity. The paper concludes with a discussion of the implications for future research in this area.

2. The conceptual model

We focus our attention on the irrigation lawn over the summer months in this analysis. In the traditional Australian suburban home, lawns make up a major proportion of irrigation demand, both because of the higher water requirement (lawns require twice as much water per square meter as garden beds, Water Corporation 2006) and because grassed area typically takes up a large proportion of the landscaped area of the suburban property. Decisions regarding the irrigation of lawn in the short run affect the general appearance of the lawn, which are reversible in the longer run when restrictions are lifted. Southern Australia is characterised by dominant winter–spring rainfall, which means that demand for irrigation is highest in summer, and restrictions are usually put into place at the beginning of a summer with little prospect of being lifted for the rest of the summer. Our attention on the short run implies that the opportunities for longer run adjustments to an increased risk of sprinkler bans, which might include for example reducing lawn area, changing to lower-water-using varieties, are excluded from the analysis. These longer term adjustments will reduce the disutility associated with sprinkler restrictions beyond the short-run impacts we assess here, where the assumed consumer goal is to achieve a certain level of lawn quality, given that the consumer is in equilibrium regarding long-term decisions about garden design including lawn size and variety.

We describe the consumer good being created by lawn irrigation (W) as the quality and general appearance of the lawn, which we call the greenness index (G). Assume that the consumer has a budget of Y for allocation to goods purchased in the short run, and a separable utility function with regards to consumption of goods purchased with Y, which can be greenness or other goods and services (O). They have a quantity of leisure time available L, for which they also derive utility:

$$U = U(G, O, L). \tag{1}$$

Assume the costs of producing green lawn c_w are solely dependent on water applied, and the cost of other consumption goods is c_o. Water can be applied by sprinkler W_s or by hand-held watering W_h. With available time T, they can allocate to leisure L or to watering the garden $l_{G.}$ The rate at which the lawn can be watered by hand is κ, that is, $W_h = \kappa.l_G$. The indirect utility function can be written as follows:

$$\begin{aligned} V = U(G(W_s + W_h), O, L) + \lambda_Y(Y - c_oO - c_w(W_s + W_h)) \\ + \lambda_L\left(T - \frac{W_h}{\kappa} - L\right)W_s, W_h, L, O \geq 0 \end{aligned} \tag{2}$$

where: λ_Y is the Lagrange multiplier for the budget constraint, λ_L is the Lagrange multiplier for the time constraint.

In the absence of sprinkler restrictions, the welfare-maximising conditions with respect to water use are:

$$\frac{dV}{dW_s} = \frac{\partial U}{\partial G}\frac{\partial G}{\partial W_s} - \lambda_Y c_w \leq 0, \quad W_s \geq 0 \tag{3}$$

and

$$\frac{dV}{dW_h} = \frac{\partial U}{\partial G}\frac{\partial G}{\partial W_h} - \lambda_Y c_w - \frac{\lambda_L}{\kappa} \leq 0, \quad W_h \geq 0. \tag{4}$$

As long as the marginal utility from water application is greater than the cost of application, then sprinkler irrigation will be applied, and the first condition in Equation (3) will be met as an equality. In contrast, Equation (4) will be met as an inequality as long as $\lambda_L > 0$. That is, as long as there is disutility from foregoing leisure to undertake hand-held watering, all watering will be done by sprinkler irrigation. It can be seen that our functional form assumes there is no utility derived directly from allocating time to hand-watering, and the cost of restrictions is the foregone leisure associated with hand-watering. Data from a household survey conducted prior to restrictions found that 34 per cent of respondents derived enjoyment from hand-watering, but only 9 per cent of households solely used hand-held watering (Nancarrow *et al.* 2002). For cases where consumers do view hand-held watering as a leisure activity, our approach would imply that we need to further nest the leisure allocation decision between hand-held watering and other activities. The decision to water by hand in the absence of restrictions may imply a combinations of factors including ample leisure time, the perception of watering as a leisure activity, a low preference for greenness and a small garden. However, given the substantial time commitment required to water lawns only by hand over the summer months there is likely to be some opportunity cost in terms of foregone leisure for the typical suburban block. We can examine the impact of leisure preferences for hand-held watering by varying the opportunity cost of time.

Introducing water restrictions imposes an additional constraint ($W_s \le \bar{W}_s$) on the indirect utility function:

$$V = U(G(W_s + W_h), O, L) + \lambda_Y(Y - c_o O - c_w(W_s + W_h)) \\ + \lambda_L\left(T - \frac{W_h}{\kappa} - L\right) + \lambda_s(\bar{W}_s - W_s). \tag{5}$$

If W_s is binding ($W_s = \bar{W}_s$), $s > 0$, we have:

$$\frac{dV}{dW_s} = \frac{\partial U}{\partial G}\frac{\partial G}{\partial W_s} - \lambda_Y \cdot c_w - \lambda_s = 0 \tag{6}$$

and

$$\frac{dV}{dW_h} = \frac{\partial U}{\partial G}\frac{\partial G}{\partial W_h} - \lambda_Y \cdot c_w - \frac{\lambda_L}{\kappa} \le 0, W_h \ge 0. \tag{7}$$

If a consumer is using sprinklers prior to restrictions, then Equation (6) will be met as an equality, and it is possible that Equation (8) may also be met as an equality. Combining Equations (6) and (7) this will occur as long as:

$$\frac{\lambda_L}{\kappa} < \lambda_s. \tag{8}$$

Equation (8) states that hand-held watering will occur if the disutility from expending leisure time on hand-held watering, measured in per unit of water applied, is less than the marginal disutility associated with the sprinkler restriction (λ_s). The conditions under which this will be satisfied include a relatively low opportunity cost of leisure λ_L, larger productivity of labour with respect to hand-held watering κ or a relatively tight constraint on sprinkler watering (λ_s is large). The factors affecting λ_s include the productivity of water in producing greenness and the consumer preference for greenness.

3. Calibration of the model

3.1 Greenness production model

The relationship between water application and the greenness of the lawn was derived from the results of experimental studies conducted in Perth over three consecutive summers for 11 turf species (Colmer and Short 2001; Short 2002). Measurements included lawn ‘greenness’, the mass of clippings obtained from mowing and meteorological data, such as daily rainfall and water (pan) evaporation rate. The irrigation regimes were characterised by the amount of water applied, expressed as a percentage of daily pan evaporation, and the application frequency, for example, daily or every second day. Greenness was measured using a chromo-meter to measure the colour of each irrigation treatment (recording the *a** green–magenta colour coordinate) and is expressed as a ratio of the *a** value for the control, being the same species of turf irrigated at 100 per cent of daily pan evaporation, which represents lush turf with no water stress. Thus greenness of 100 per cent implies a healthy green canopy while 0 per cent greenness means a yellow–brown dead appearance. They measured greenness over the course of the summer; we used the end of summer values for Buffalo species, one of the most common varieties used in Perth. Data for irrigation treatments representing 30, 40, 50, 60 and 100 per cent pan evaporation were used to estimate a production function according to Equation (9):

$$G = \begin{cases} 0 & \text{if } I \le 20 \\ [(-62.29 + 3.02I)^{-20} + (0.06 + 93.60I)^{-20}]^{-0.05} & \text{if } 20 < I \le 100 \\ 100 & \text{if } I > 100 \end{cases} \qquad (9)$$

where I is the mean irrigation level expressed as a percentage of daily pan evaporation (% E_{pan}). Figure 1 shows that Equation (9) describes well the greenness–irrigation data of Colmer and Short (2001).

The quantity of water W used to achieve a certain irrigation level I, which determines greenness, is:

$$W = \frac{I \cdot E_{\text{pan}} \cdot A}{e} \qquad (10)$$

where, E_{pan} is the total pan evaporation over the 90 days of summer, in metres; A is the lawn area in m^2; e is the irrigation efficiency.

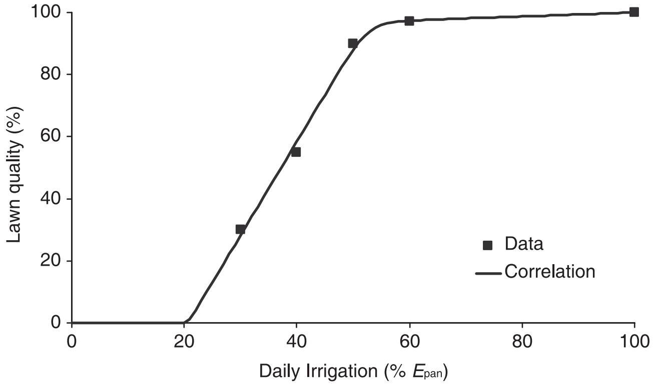

Figure 1 Lawn quality–irrigation correlation for daily irrigation.

Table 1 Parameters used in model calibration

Equation 10			
E_{pan}	0.799 m	December to February total class A pan evaporation for Bureau of Meteorology's Perth Metro station, averaged over five summers, 2000/01–2004/05†. Pan evaporation is a standard measure that reflects the amount of water which would evaporate from an open pan of water	
Lawn size A	170 m‡	Assumed lawn area derived from analysing survey data referred to in ARCWIS (2002)	
Efficiency E	75%	Mid-range efficiency for sprinklers (Connellan 2002)	
Economic parameters			
Pre-restrictions lawn maintenance cost, summer	\$241	Based on weed, feed and mowing costs for a typical suburban lawn‡	
2 days per week restrictions lawn maintenance	\$193	Saving due to reduced frequency of mowing, from weekly to fortnightly	
Water price	\$0.91/kL	Marginal price at water consumption of typical suburban block, based on ARCWIS (2002) consumption data and Water Corporation's inclining block tariff§	
Cost of watering, c_w	\$2.39/kL	Marginal cost of lawn maintenance, \$1.48/kL plus the cost of water	
Expenditure per summer other than lawns, \$ per household	\$5511	Derived from ABS (2005)	
Time available	720	Hours per household per summer	
Calibration of utility function	**Typical preference for greenness ($50\%\ E_{\text{pan}}$)**	**High preference for greenness ($75\%\ E_{\text{pan}}$)**	**Low preference for greenness ($25\%\ E_{\text{pan}}$)**
Baseline water use on lawns (kL)	92	138	46
Baseline greenness (%)	88	98	13
Greenness utility parameter α	0.021	0.49	0.0020

Sources: †http://www.nrm.qld.gov.au/silo/, ‡Based on interviews Terry Solomon, Floreat Lawn Services (2006); Benjamin Mustard, Evergreen Turf Farm (2006), §http://www.watercorporation.com.au/A/accounts_rates_metro_res.cfm.

The amount of labour required to water by hand, defined as κ in Equation (2), determined by the system flow rate, and is 1.8 kL/h. Table 1 lists the parameter values for Equation (10) used in this study.

3.2 The cost of lawn greenness

The cost of producing and maintaining lawn greenness is made of up water costs and maintenance costs. Lawn maintenance cost generally comprises mowing, fertilising and weeding. Colmer and Short's (2001) experimental data on volume of grass clippings in relation to irrigation treatment revealed a linear relationship between water and production, so we assumed a linear relationship between irrigation and mowing cost. We interviewed a turf production company and a mowing company to develop cost assumptions for lawn maintenance at two levels of irrigation, based on pre-restrictions experience and the current 'two day per week' water restrictions (Terry Solomon and Benjamin Mustard, pers. comm., 2006), and then estimated a straight-line relationship as a function of irrigation. These data are reported in Table 1. The total unit cost of water is the sum of these lawn-maintenance costs and the direct price of water. Perth consumers face inclining block tariffs, and marginal water costs vary between \$0.45 and \$1.2/kL, depending on the total level of household consumption. We used a marginal price of \$0.91/kL which is the price that is likely to be paid by a consumer with an average sized household and the garden watering quantities we analyse in this study.

3.3 Parameters of the utility function

Since we are focusing on short-run decisions regarding allocation of time and money, we use total household expenditure on items that could be regarded as flexible to represent the budget constraint. The total budget over the 12-week summer irrigation period was based on a representative weekly budget. Itemised data on household expenditure (Australian Bureau of Statistics 2005) was used to distinguish between variable weekly expenditure and long-term and durable items including housing and utilities, furniture, clothing and insurance.

To calibrate the utility function, we assume a nested Cobb–Douglas functional form as follows:

$$U = (G^{\alpha} \cdot O^{1-\alpha})^{1-\gamma} L^{\gamma}. \tag{11}$$

The parameter γ was based on the ratio of the value of leisure time to 'full income' that is the sum of leisure time plus cash expenditure. The value of time for an individual in a given situation is conditioned by what activities are being traded-off (Cesario 1976), In travel cost land transportation literature the value of travel time is generally taken to be equal to one-third the average wage rate (as reported in the US census and cited in Cesario 1976). However, Larsen and Shaikh (2004) provide evidence to suggest that the value of recreation time is largely independent of the wage rate, and reported a mean value of recreation time to be around 50 per cent of the mean wage rate. Other empirical studies of resource allocation have estimated out-of-home leisure time to be nearly equal to the wage rate (e.g. Kato and Axhausen 2005). One of the major differences between leisure studies, which usually apply to 'weekends' or 'holiday' time, and this study is that households will be required to water lawns in limited time available on weekday evenings if they are to obtain the greenness they require in the presence of sprinkler bans, thus their opportunity cost of time may be higher than revealed in empirical recreation studies. On the other hand, some households may view hand-watering as a pleasurable activity. We explore the implication of value of time using sensitivity analysis, by multiplying the mean wage rate by 33, 50 and 100 per cent.

The total time available was based on a daily amount of four hours multiplied by the length of the evaluation period, being the 90 days of peak summer (December to February) conditions. The estimate of 4 h per person day is based on an allowance of 9 h for working and commuting, 8 h for sleeping and 3 h for other obligatory activities. We assume two persons per household, giving us a total time of 720 h over the summer. When restrictions are in place, we assume that households allocated labour to watering garden beds (total requirement being 25 h over the summer under complete sprinkler bans) before any time is allocated to watering lawns. This is because perennial plants in garden beds are likely to die without water, incurring high replacement costs, whereas the impacts on lawns are short-term loss of greenness, which can be recovered subsequently by applying irrigation.

To represent three different levels of 'greenness preference' we calibrated the utility function for three baseline water consumption/greenness levels. Nancarrow *et al.* (2002) found that 60 per cent of Perth householders watered every second day in the absence of restrictions, 16 per cent watered every day and 23 per cent watered twice per week or less. Based on standard watering times these frequencies correspond to 50, 75 and 25 per cent of E_{pan}, denoted as 'typical', high greenness and low greenness preferences, respectively. From the greenness production function we can find the corresponding level of greenness for the calibration of the utility function for each type of consumer, as shown in Figure 2. It can be noted that at the 75 per cent E_{pan} level,

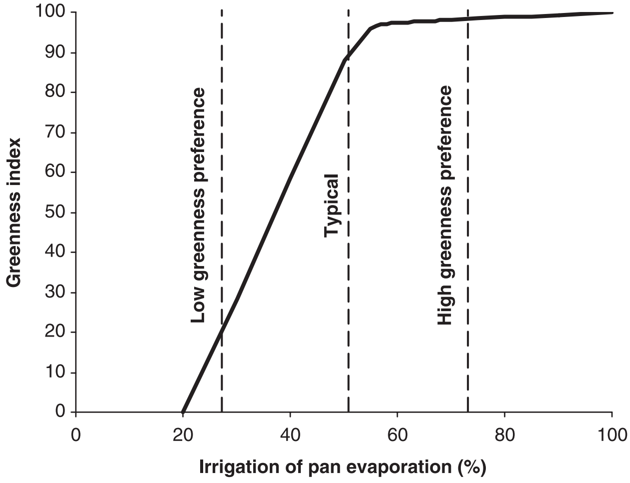

Figure 2 Calibration of baseline pReferences.

the slope of the greenness production function is very flat implying that if householders are properly informed about the shape of this function, they must have very inelastic preferences for greenness. The parameter value α in the utility function was determined empirically to return the baseline choice sets. The utility function parameters, as well as other key assumptions, are reported in Table 1.

The model was calibrated in Excel, and the utility-maximising response to water restrictions in terms of water use, greenness, and consumption of other goods and leisure was determined using the Excel Solver. A range of different restrictions levels was analysed. From a current policy perspective the two main levels of water restrictions that were of interest were the current mild restrictions, which allow sprinklers to be used two days per week, and a complete sprinkler ban, which only permits hand-held watering. Having solved for the optimal response to the restriction we calculate the welfare cost as the compensating variation, the level of income that would be required to make the consumer indifferent to the demand management policy and the ‘no restrictions’ case. However, since the regulated water utility would be required to pass any excess revenue back to the consumer, we also calculate the net welfare effect assuming the excess revenue is handed back in a lump sum payment to each consumer in proportion to the excess of their bill relative to the unrestricted case.

4. Results

4.1 An illustration of the leisure–greenness substitution choice

The nature of the trade-offs associated with sprinkler restrictions are illustrated in Figure 3, using the case of ‘typical preferences’ and a time cost of 50 per cent

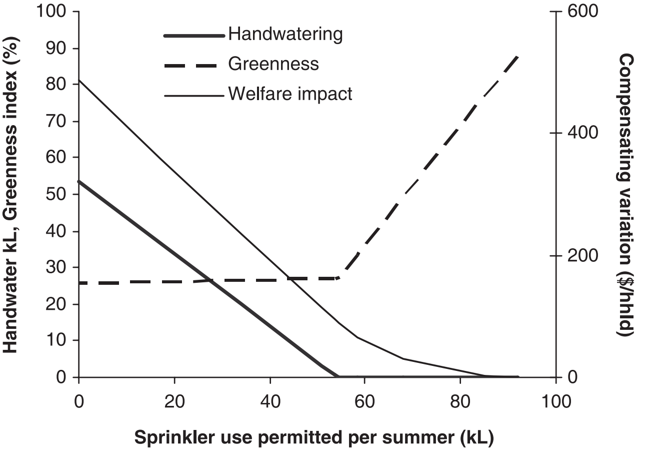

Figure 3 Illustration of the substitution effects associated with sprinkler restrictions, case of typical greenness preferences, time cost is 50 per cent of wage rate.

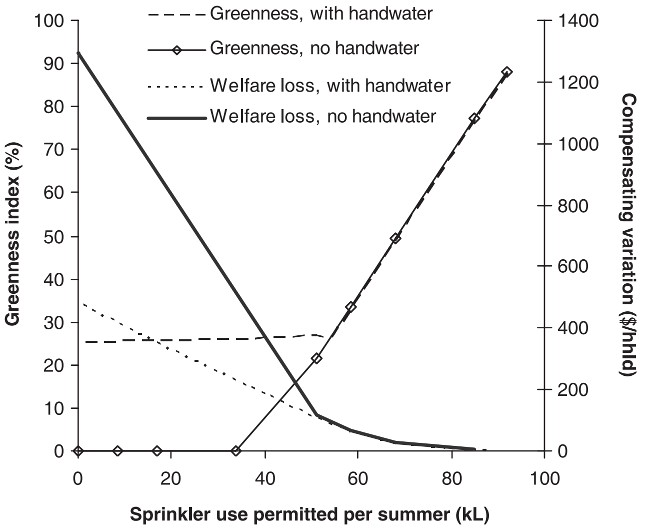

Figure 4 The effect of hand-watering on welfare and greenness.

of the wage rate. Moving from the right to the left of the figure, the amount of sprinkler watering permitted is reduced from the unconstrained level to a complete sprinkler ban. The impact on lawn greenness and welfare is shown. As water application is reduced, greenness declines and the welfare cost of restrictions increases. As the welfare cost begins to increase at an increasing rate there is a point where hand-watering becomes preferable to continued reduction in lawn greenness. This switching point is better illustrated in Figure 4, which compares the welfare cost and greenness associated with sprinkler bans with the case where hand-watering substitution is not permitted.

The dashed lines in Figure 4 show the baseline case where substitution for hand-watering is possible. The solid lines indicate the greenness and welfare impacts that would arise if hand-watering was also banned. Greenness continues to fall as sprinkler use is restricted, rather than plateauing as in the case where substitution is permitted. This leads to a significantly higher welfare loss.

4.2 Effect of different assumptions on the substitution response and efficacy of the policy

The nature of the consumer problem was demonstrated using a utility function calibrated for the average consumer and using a time cost of 50 per cent of the wage rate. The impact of alternative assumptions on the substitution response associated with water restrictions is demonstrated graphically in Figures 5 and 6. The first figure shows the impact of preferences on water use, where preferences refer to different calibration points associated with high, typical and low baseline water use on lawns. Those consumers who are currently practicing high water-application rates will substitute hand-watering

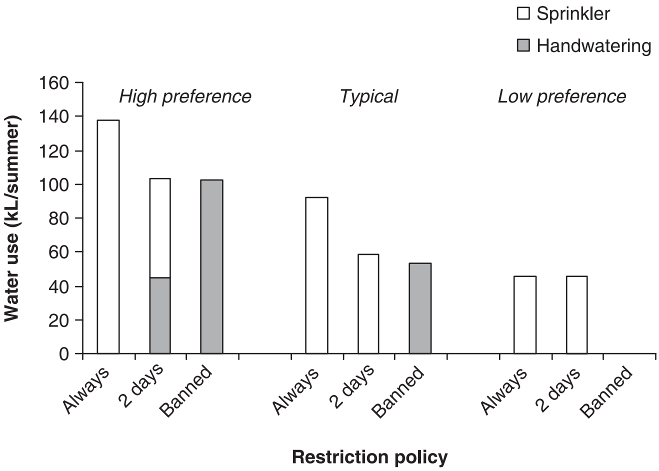

Figure 5 Impact of preferences on substitution of hand-held watering, for two restrictions policies compared to unrestricted.

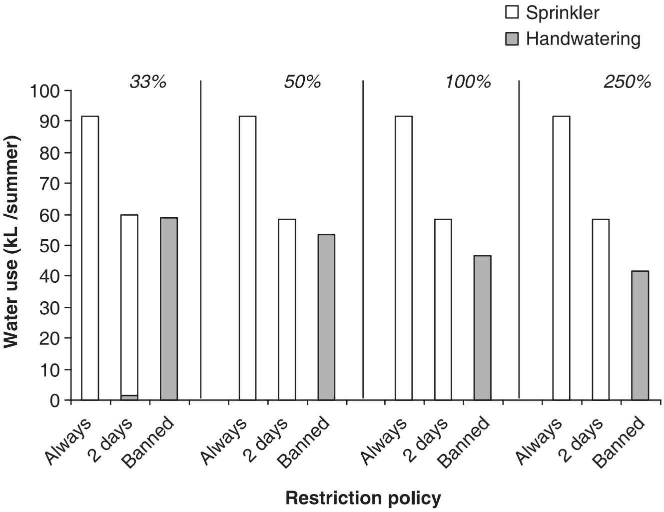

Figure 6 Impact of leisure time costs (% wage rate) on substitution of hand-held watering, for two restrictions policies compared to unrestricted.

when moderate sprinkler restrictions are in place, in order to maintain a high standard of lawn greenness. They also use substantially more water during a sprinkler ban, applied by hand. Those who reveal a very low preference for greenness via low baseline water application are unlikely to substitute any hand-watering when restrictions are in place. In the case of a total sprinkler ban they simply give up watering and let their lawns go completely brown. Consumers with preferences that we believe are most typical of the Perth consumer are likely to substitute hand-held watering when complete sprinkler bans are in place, but not when they are permitted to use sprinklers two days

Table 2 Impact of preferences on welfare cost and efficiency of policies

	Water use (kL)	Water reduction (%)	Net welfare cost ($)
1. ‘Typical preferences’, time cost 50% wage rate			
Unrestricted	92		
2 days per week	58	36	67
Ban	53	42	487
2. ‘High preference’, time cost 50% wage rate			
Unrestricted	138		
2 days per week	103	25	664
Ban	103	25	1590
3. ‘Low preference’, time cost 50% wage rate			
Unrestricted	45		
2 days per week	45	0	48
Ban	0	100	19
4. ‘Typical preference’, time cost 33% wage rate			
Unrestricted	92		
2 days per week	60	35	66
Ban	59	36	347
5. ‘Typical preference’, time cost 100% wage rate			
Unrestricted	92		
2 days per week	58	36	67
Ban	47	49	871

per week. For this typical consumer, there is very little additional reduction in water use associated with upgrading from a two day policy to a complete sprinkler ban.

The effect of alternative assumptions regarding time cost is illustrated in Figure 6. As would be expected the amount of substitution for hand-watering is reduced as the time cost increases. At the very low time cost of 33 per cent of the wage rate, a figure typically used in recreation studies, there is a very small substitution of hand-watering under the two days per week sprinkler policy.

4.3 Welfare impacts of sprinkler restrictions policies

More detail regarding the welfare costs and effectiveness of pricing and sprinkler restrictions policies, and the influence of preferences on these costs, is shown in Table 2. The percentage reduction in water use is smaller for consumers with high preferences for greenness and the welfare impact of sprinkler bans is substantially larger than for the ‘typical’ preference set. For example, the cost of a sprinkler ban is estimated to be $1590 when time is valued at 50 per cent of the mean wage rate. However, as noted previously, the calibration point for this consumer was at the very flat component of the production function indicating extremely high preference for greenness, which could in fact be the result of ignorance regarding the productivity of water.

The influence of time costs on the response to, and welfare costs of sprinkler restrictions is also shown in Table 2. Under a complete sprinkler ban, there is less substitution for hand-watering as time costs increase, and a larger net impact on welfare. These welfare costs range from $347 per household when time costs are lowest, to $871 per household when time is measured at the full wage rate.

Because there is no substitution for hand-held watering at the time costs of 50 and 100 per cent under a two-sprinkler-day per week policy, the water use and welfare impacts are the same for all these cases. The small substitution for watering in the case of a consumer with a time cost of 33 per cent of the wage rate means that they can mitigate the welfare impact slightly.

It can be noted that Perth consumers in some areas can access groundwater using backyard bores which costs between $2500 and $10 000 to install depending largely on depth to water and once installed cost only 4 cents/kL to run compared to spending 91 cents for scheme water (Lieb *et al.* 2007). Their analysis indicates that for conventionally sized lots there are economic gains to the household from adopting a bore technology before the benefits of avoiding sprinkler restrictions are considered. In areas where bores are more costly to install, the results presented here indicate that preferences for greenness and willingness to pay to avoid restrictions may be sufficient to induce adoption especially for those with a high greenness preference.

4.4 Impact of efficiency of hand-watering on results

There are a number of reasons why a restriction policy may impose technical inefficiencies on the system. For example, the current sprinkler restrictions used in Perth are implemented by assigning permitted watering days (two per week) according to the street number of the property. However, Colmer and Short's (2001) experimental data used to support the present study suggests that the same total amount of water, applied more frequently in smaller quantities, may have higher productivity. Similarly, there may be differences in the application efficiency of different watering methods. Poor uniformity of application associated with hand-held watering may result in over application of water in some areas, and under application in others, requiring more water to establish the same level of greenness. Whilst the technical efficiency of alternative mandated outdoor watering regimes is beyond the scope of this paper, the general principles can be demonstrated by examining the impact of a sprinkler restriction policy where technical efficiency of hand-held watering is lower than for sprinklers. Results shown in Figure 7 compared the baseline, where efficiency is 75 per cent for both sprinkler and hose; with the case where hand-held watering is assumed to be less efficient (assuming 60 per cent efficiency).

Figure 7(a) demonstrates the impact of the hand-held water application efficiency on the response to sprinkler restrictions. Whilst the point at which watering commences is deferred slightly, the less efficient system results in a higher rate of hand-watering as sprinkler use is further reduced. The welfare

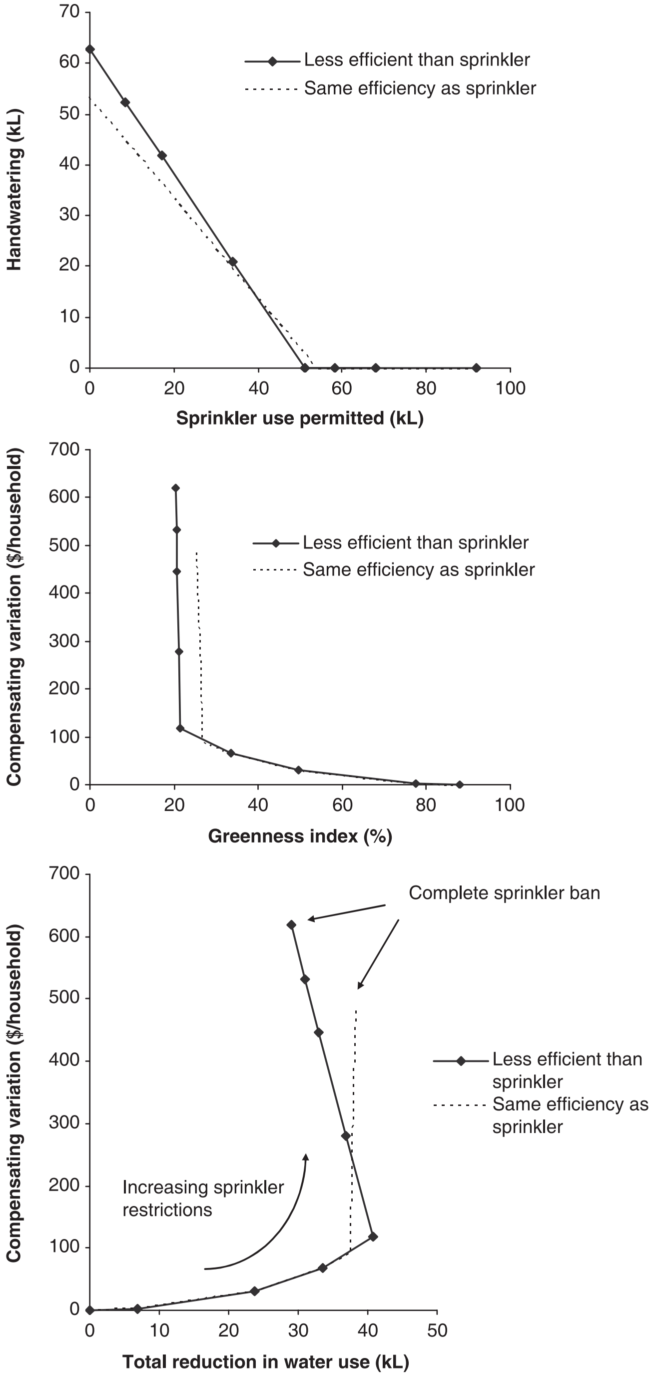

Figure 7 (a) Impact of watering efficiency on hand-held watering response. (b) Relationship between greenness and compensating variation, for two hand-held watering efficiency assumptions. (c) Welfare cost and water saved from water restrictions, two different hand-watering efficiency assumptions.

impact associated with the two policies, expressed as a function of greenness, is shown in Figure 7(b). The less efficient system also results in lower greenness, and imposes a higher welfare cost on the consumer as they attempt to make up for the lower water productivity by increasing watering time. The relationship between the welfare impact and the total amount of water saved from the policy is shown in Figure 7(c). As the sprinkler restrictions become more severe, water savings are achieved up until the point where it becomes optimal to substitute for hand-watering. Beyond this point, the main impact of tightening the restriction level is to cause a welfare loss associated with reduced leisure time; but in the case of the less efficient hand-watering scenario, the substitution for hand-held watering actually leads to a policy failure – less water is saved at a higher cost to the consumer.

5. Conclusions, limitations and extensions

Stated preference techniques have been used previously to assess willingness to pay to avoid restrictions. We have presented an alternative approach which makes use of knowledge about the relationship between watering and lawn quality, and demonstrates the nature of the trade-offs between sprinkler, hand-held watering and leisure time. This has allowed us to explore the factors that affect not just the welfare cost of outdoor water restrictions, but also their efficacy. We showed that the preferences towards lawn greenness, and the time cost, or disutility associated with hand-held watering, will influence the extent to which a sprinkler restrictions policy is effective. For example, we have estimated that the household welfare costs of a sprinkler restriction appear to be less than $100 per season when mild (two days per week) sprinkler restrictions are in place, and may range between $347 and $870 per season when a complete sprinkler ban is in place, over the range of estimates we examined for the opportunity cost of time. The associated water savings are around 36 per cent of current consumption for the mild restrictions, compared to only 42 per cent when a complete sprinkler ban is in place.

Given the fact that lawn irrigation is the largest single type of water demand in many Australian urban contexts, and that the reliability of supplying this demand is used to determine the timing of future supply augmentation, further investigation of preferences for and efficacy of outdoor water policies is warranted. Some of the limitations of our work that could be investigated in future research include lack of information regarding the nature of consumer preferences for greenness, lack of evidence on the true cost of time associated with hand-held watering, and the assumption of perfect information. Since our approach explicitly examines the productivity of water in producing greenness, one area where further research may have policy relevance is in the design of information campaigns to address misinformation regarding the productivity of watering technologies and regimes.

We examined the short-run values associated with sprinkler restrictions assuming long-term decisions concerning garden layout, lawn size and variety and irrigation technology were held constant. However, since our approach allowed us to incorporate the technical relationship between lawn greenness and irrigation, it could easily be extended to examine incentives for adoption of more efficient irrigation technologies and lawn varieties with different water response relationships, as well as the influence of the risk of sprinkler bans on such investment decisions. The basic concept behind the approach is that water is an intermediate good used by householders to produce consumption goods, and this concept might also have application in the study of technology adoption that affects water use inside the home.

Acknowledgements

This research was funded by the CSIRO Water for a Healthy Country Flagship.

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