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Maintaining the Common Pool: Voluntary Water Conservation in Response to Increasing Scarcity

Emma Aisbett and Ralf Steinhauser

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Australian National University

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Abstract

Water is a classic common pool resource, especially during drought. This paper studies the impact of changing storage levels on urban water usage in the context of a prolonged drought and an extensive public information campaign which emphasized communal responsibility for maintaining 'dam levels'. We identify a substantial voluntary conservation response to changing storage levels. The paper thus contributes a rare piece of real-world, behavioral evidence that voluntary conservation varies with the need for such action. Our findings also imply that estimates of price elasticity may be biased and welfare costs of mandatory restrictions may be overstated in many studies.

Keywords: common pool resources, voluntary conservation, warm glow, water use, demand management

JEL Codes: Q25 Q21 D64

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1 INTRODUCTION

Many social issues, and almost any environmental issue, can be understood as a common pool resource problem. Thus it is no surprise that there is an extensive literature devoted to the question of how common pool resources can be sustainably managed. When group size is large and social connections are weak, conservation of resources managed under a common property regime relies on private, voluntary actions and is driven principally by the desire for the 'warm glow' of having 'done good' (Andreoni, 1988; Ostrom et al., 1999). Models of such voluntary action - such as Brekke et al.'s (2003) model of moral motivation - assume that motivation is increasing in the public value of the action. This assumption is consistent with laboratory and survey-based evidence, but to the best of our knowledge it has not been shown using representative data of observed behavior in a real-world setting.[1]

One reason for the lack of studies examining the responsiveness of voluntary action to the size of the social problem is that variation in the severity of an issue - for example biodiversity or climate change - is often difficult to identify on a suitable time- or geographical-scale. We propose that changing water storage levels during drought provide a rare example of such natural variation - and thus an excellent opportunity to test if real-world behavior is consistent with theories of moral motivation.[2] This paper exploits this opportunity. It examines the response of water usage to changing storage levels in the context of a prolonged drought and an extended campaign to inform consumers both of the current storage levels, and of their responsibility to maintain them.

The policy context of this study is clearly urban water demand management - an important area of study in its own right, and the subject of an extensive literature.[3] Our paper is most closely related to studies of the effectiveness of information campaigns - which number relatively few despite the fact that information campaigns are a ubiquitous policy response to drought. The existing studies have generally found information campaigns have statistically significant but economically small effects on water consumption.[4] One reason for these relatively modest effects may be that the introduction of an information campaign can only affect awareness of and subjective beliefs about the severity of the water-scarcity problem. The current paper, in contrast, studies the impact of changes in an objective measure of scarcity on water useage by an already highly-informed population.

[1] See Isaac and Walker (1988) for an early contribution to the laboratory-based literature. See Kantola et al. (1983) for a water-conservation example from the survey literature.

[2] Voluntary decreases in driving in response to advertized air-quality deterioration would seem to be another potential place to look. However, the one paper on this topic of which we are aware claims that actual data are too noisy and thus relies on survey responses (Henry and Gordon, 2003).

[3] Dalhuisen et al. (2003) provide a meta-analysis of 296 different price elasticity estimates for urban water demand.

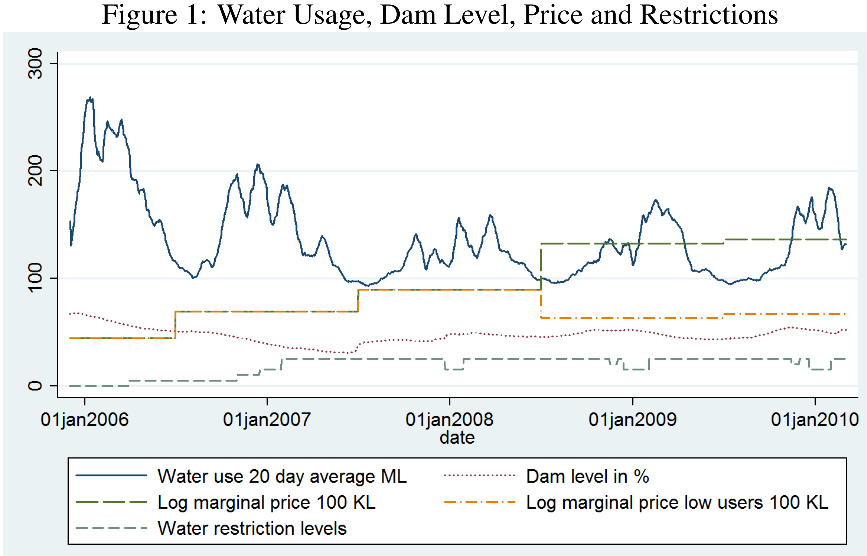
[4] Notable recent examples include Michelsen et al. (1999), Halich and Stephenson (2009) and Ferraro et al. (2011). See Syme et al. (2000) for a survey of earlier literature.

Our finding that voluntary conservation can be substantial and is responsive to dam storage levels has important implications for both the literature and the lively policy debate on urban water demand management. These implications are discussed in the results (section 4) and conclusion (section 5). We turn first to a description of our data, physical, and policy context (section 2) and empirical approach (section 3).

2 Data and Background

Our water usage data from the Australian National Capital region provides an exceptional opportunity to study how voluntary, uncoordinated actions respond to changes in the objective need for action, on an issue whose importance was widely recognised in the community. The sample period - from December 2005 to March 2010 - covers the end of a decade-long drought in South-Eastern Australia. The prolonged drought and consequent shortages in water reservoirs were frequently in the news, and a number of smaller towns had completely run out of water and been forced to import it. The Managing Director of the water-supply utility for our study area described the 2006 dam levels as "dangerously low",[5] and there was serious debate at the time about whether to use recycled waste water as drinking water (a practice which is unprecedented in Australia).[6] The evolution of storage levels over our sample period is plotted in green in Figure 1.

Figure 1: Water Usage, Dam Level, Price and Restrictions



Awareness raising and the assertion that every consumer has responsibility for maintaining storage levels were key components of the water-scarcity policy response. In the Capital region, water storage levels (percent full) were reported weekly in the leading newspaper and on the television news during our sample

[5] http://www.canberratimes.com.au/news/local/news/general/climate-blamed-for-high-water-use/1815827.aspx

[6] http://www.abc.net.au/water/stories/s1922096.htm

and for two years prior.[7] In the latter half of our sample electronic roadside signs displaying daily storage level, actual, and target consumption were positioned along the five major arterial roads. A survey by the water utility a few months prior to our sample period found that 98% of participants said they were aware of the current conservation campaign and, of these, 77% said the campaign had at least some impact on their consumption behaviors (Results from ActewAGL surveys, reported in Yardley (2009)).

The information campaign was complemented by both mandatory restrictions on outdoor water use, and price changes. There were five restriction levels, all of which we observe in our sample. Stage 1 - which began prior to the start of our sample - consists of relatively minor water restrictions. The somewhat stricter Stage 2 was only briefly in place before Stage 3 was introduced at the beginning of 2007. Stage 3 restrictions are very tough and forbid the use of sprinklers, watering lawns and topping up pools, and only allow watering plants with a trigger nozzle hose at restricted times. Stage 3 lasted to the end of our sample and is only interrupted by short summer and spring clean exemption periods. A detailed explanation of the water restriction categories can be found in the Appendix. The timing of the changes in restriction levels are plotted as dashed line in Figure 1.

ActewAGL employs increasing block pricing, meaning that the relevant marginal price depends on consumption.[8] Marginal price increased for all users each year in our sample, except for those consuming 100-200 kiloliters per year (kL/yr) who saw a decrease in marginal prices in July 2008 due to the elimination of one of the block-pricing levels. Marginal price for the average household (consuming 232 kL/yr)[9] is plotted as long dashed line in Figure 1. Note that price changes are permitted annually in July and this is helpful for our identification of the role of the different policy variables. In particular, the major change in restriction levels (from Stage 1 to Stage 3) occurred in January 2007, separating it from price changes by over 150 daily observations.

The solid line in Figure 1 plots a 20-day moving average of the daily aggregate water usage.[10] Aside from seasonal variation, the steep decline in consumption from the start of our sample through to mid-2007 is evident, followed by stabilization or perhaps gradual increase in the subsequent years. It is interesting to note that this gradual increase in usage from the 2007 low occurred despite the maintenance of Stage 3 restrictions

[7] Actew's information campaign also included television advertisement, specific publications, mail drops, advertising on posters and in newspapers such as in The Canberra Times.

[8] As with many water supply utilities around the world, price changes are regulated to ensure monopoly profits are not reaped by the supplier.

[9] Troy et al. (2006) produced statistics for average annual household consumption by type of dwelling. With separate houses using 319 kiloliters (kL/yr), semi-detached dwellings using 193 kL/yr and flats 138 kL/yr.

[10] Although we plot 20-day moving average consumption in Figure 1, actual daily usage is used in our regression analysis. Daily data has two advantages compared to the monthly data used in previous studies of non-price demand management measures. Firstly, the higher frequency significantly reduces the extent of colinearity of the multiple policy changes that were made, an issue which has plagued most studies (Syme et al., 2000). Secondly, it allows for the inclusion of detailed weather controls as discussed below.

and increases in average price in subsequent years. We propose that the reason for this gradual increase in consumption is the accompanying slow recovery in storage levels, leading consumers to somewhat relax their water conservation efforts.

A key danger of such casual empiricism is, of course, the omission of other important variables. In particular, we may be concerned that higher rainfall in 2007 - which led to the initial increase in dam levels - also suppressed consumption in that year. Controlling for local weather conditions is particularly important in Australian samples, for which weather typically explains a large part of the consumption variation.[11] In our study region over 90% of households live in detached and semi-detached dwellings[12], and within this group outdoor water use accounts for 43% of water consumption.[13] We obtained weather data from the Bureau of Meteorology's Canberra airport weather station.[14] The observations include daily weather variables such as sun-hours, precipitation, temperature, evaporation and many more.[15] We take considerably more care to control for weather than previous water-demand studies. We use daily (c.f. monthly) usage and weather data, and we control for contemporaneous and lagged weather variables, including moving averages and month dummies.

We may also be concerned that the gradual increase in total usage is due to population growth. Thus we control for population using quarterly estimates for the region from the Australian Bureau of Statistics.[16] Summary statistics of our data by year from winter to winter season are provided in Table 1. The average daily usage dropped by 36% from 2005/2006 to 2007/08. Consumption increases slightly in the subsequent years despite the increased precipitation. Dam levels reached their lowest point in June 2007. Marginal water prices for the average household have more than doubled over the observation period from under two dollars to almost four Australian dollars. In 2010 dollar terms prices increased by 150% from $1.56 per kiloliter at the start of our observation period to $3.9 per kiloliter in 2010.

[11] We use a large number of weather variables in our final specification. All of these are highly significant and together explain 41% of the water usage variation in the data.

[12] In the ACT 81.5% are separate houses, 10.7% semi-detached dwellings and 7.6% flats (see ABS's Australian Social Trends - Housing Table 2.8 available at: http://www.abs.gov.au/ausstats/abs@.nsf/mf/4102.0)

[13] See ACT Goverment (2004, page 22).

[14] This is the main weather station in Canberra with the most detailed and uninterrupted weather data from the region since 1939. It was relocated within the airport proximity in December 2010.

[15] The weather station records a total of 57 daily measures and statistics. For a complete list see: http://reg.bom.gov.au/climate/dwo/IDCJDW2801.latest.shtml

[16] From the ABS's Australian Demographic Statistics publication. The estimates are based on the ABS's last 2006 Census and can be found here: http://www.abs.gov.au/ausstats/abs@.nsf/mf/3101.0

Table 1: Summary statistics

	2005/06	2006/07	2007/08	2008/09	2009/10
Mean daily usage (ML)	194	140	119	123	130
(Std. Dev.)	(54.4)	(39.2)	(21.8)	(27.2)	(34.2)
Mean dam level (%)	58.5	40.5	44.8	47.9	49.5
Minimum dam level (%)	50.8	30.8	37.9	43.1	43.2
Maximum dam level (%)	67.8	50.8	49.7	52.1	54.5
Average rain per day (mm)	1.26	1.17	1.25	1.4	1.6
(Std. Dev.)	(4.9)	(3.9)	(3.9)	(4.7)	(5.5)
Percent rain days (%)	17.5	26.3	29.0	30.7	31.3
Marginal cost in $/KL	1.56	1.99	2.45	3.76	3.9

3 Empirical Approach

To identify the impact of water scarcity on consumption we regress (log) usage on dam storage levels, controlling for outdoor restrictions, price changes, and exogenous demand determinants such as weather and weekday. Our base specification has the form:

$$\ln(y_t) = \alpha_0 + \alpha_1 Damlevel_{t-1} + Z_t'\beta + X_t'\delta + \varepsilon_t$$

where $\ln(y_t)$ is the log of per capita water usage in megaliters at time t. α_0 is the coefficient on a constant term. $Damlevel_{t-1}$ is the previous day's combined storage reservoir level (% full). *Damlevel* is lagged one day to avoid reverse causality from usage to storage levels. As argued above, dam levels have an indirect effect through demand management policies. However, they may also have a direct affect on voluntary efforts as they conveying the urgency of water conservation to the consumer. Since we control for induced policy changes, we interpret α_1 as the magnitude of the direct effect of dam levels on consumption. α_1 is thus our main parameter of interest. Z_t represents a vector of water demand management policies. It includes the log marginal price of a kiloliter of water in 2009 AU$ for average users and low-end users at time t. Including price for both types of user was important since the price changes did not always move in the same direction. Z_t also includes a dummy variable for each restriction level equal to 1 if the respective outdoor water use restriction is in place. Stage 3 restrictions is the excluded restriction level in the regressions. The coefficients on the other restriction levels present their relative effect on consumption compared to Stage 3. X_t includes all other control variables. These include an extensive set of variables from the Bureau of Meteorology to control for as much of the variation in consumption due to changes in weather. Weather controls included are rainfall, 5 days of lagged rainfall, 20 day moving-average rainfall, sun-hours, evaporation, 3 days of lagged evaporation, 20 day moving-average evaporation, the maximum temperature and yesterday's maximum temperature. As discussed above this extensive set of weather controls is important in light of the significant outdoor component in water usage in our sample and the direct impact of weather on storage levels. In addition to weather controls, X_t includes day-of-week dummies due to systematic variation in comsumption patterns across the week. This is important to account for as we find significant variation across days. Generally people use less water during the week relative to the weekend. Average water use is highest on Sundays and lowest on Fridays. Finally X_t also includes month dummies to control for seasonal variations in water usage not captured by the weather controls. ε_t is a normally distributed error term which tests revealed as serially correlated and heteroskedastistic. Thus we employ the Newey and West (1987) estimation of our covariance matrix to get corrected standard errors.[17]

Checks of the robustness of the base specification are discussed with their results in section 4.

4 Results

The main results of the paper are presented in Table 2. The first column in Table 2 represents the correlation of (lagged) dam level with consumption, controlling for all weather and other exogenous controls, but no policy variables. The coefficient of 0.011 suggests that the combined policy-induced and voluntary response to a 10% decrease in dam level would result in a demand decrease of around 11%. Moving across the columns we progressively add policy controls. As we expect, the coefficient on dam level decreases, but even with a comprehensive set of policy controls remains statistically and economically significant. Our base (and preferred) specification is in column 3. The dam level coefficient of 0.0055 in our base specification indicates that a 10% decrease in dam level will induce voluntary conservation reductions of around 5.5%. Thus the dam level change from 60% to 30% in our sample is estimated to have resulted in demand reduction of around 17%.

Columns 4 and 5 of Table 2 are the first of our robustness checks. In column 4 we control for the heightened awareness campaign which included the introduction of roadside signs. Our assumption had been that this campaign would have little effect as the population was already saturated with water conservation awareness messages. This assumption is validated by the near-zero coefficient on the "Roadside signs" dummy. Column 5 controls for the water-use target of the utility. This seasonally varying target was set jointly by the utility and government at the start of each year in accordance with the dam levels. We include

[17] Following a common practice as a simple rule suggested by Greene and Zhang (2003, page 267) Newey-West is implemented with a bandwidth of $B = (N)\,1/4$ rounded up to the next integer. The bandwidth in our case with $N = 1548$ is $B = 7$.

it in column 5 as a robustness check to ensure that we capture any unobservable elements of the utility's demand management efforts - most notably those aimed at the (few) non-residential customers. Target level was not included in our base regression as it has a high degree of colinearity with other policy variables - particularly the restriction level. Furthermore, an event study reported in the working paper version of this paper finds no evidence that target level has any causal effect on usage.[18] The combination of colinearity with other controls and lack of causal effect leads us to suspect that inclusion of target levels causes downward bias in estimates of the other coefficients. As we would expect, column 5 shows that the inclusion of the water-use target decreases the explanatory power of the other policy variables and of the dam level. However, even this (downward biased) coefficient on the dam level is highly economically and statistically significant.

The magnitude of the coefficients on price also decreases as expected when we control for additional policy variables, though the estimates in all columns lie comfortably within the range reported in the literature. Dalhuisen et al. (2003) find a mean of -0.41 and a median of -0.35 in a meta-sample of 314 price elasticities from 64 studies. In our base specification the elasticity estimate for the low-user and average-user marginal costs are around -0.27 and -0.20 respectively. To compare these figures to the literature (which generally has disaggregated data and therefore a single relevant marginal cost) we need to add the coefficients together.[19] Thus our equivalent total price elasticity estimate is -0.47. This lies between recently estimated Australian short-run marginal price elasticities of -0.35 by Grafton and Kompas (2007) for Sydney and the -0.51 estimated by Hoffmann et al. (2006) for Brisbane, but is higher than the -0.17 estimated for Sydney by Grafton and Ward (2008).

The estimated effect of less strict restrictions on outdoor uses - compared to the excluded Stage 3 restrictions - was relatively small. The 'summer exemption' and 'spring clean' appear to have no discernible effect on consumption. Stage 2 restrictions are associated with up to 12% more consumption, but Stage 1 - which should be the least restrictive - is only associated with up to 7% more.[20] It is difficult to place these results relative to the literature since a dummy variable is generally included for 'any restriction' (see for example Grafton and Ward, 2008; Kenney et al., 2004; Renwick and Green, 2000). However, according to Ward (pers. comms.), although Grafton and Ward (2008) found the introduction of mandatory restrictions

[18]See Aisbett and Steinhauser (2011).

[19]The intuition of adding the two elasticity estimates can be obtained from the thought experiment of calculating the effect of a uniform price increase which increased both marginal costs by, say, 10%.

[20]This latter result, however, is not particularly robust as is demonstrated in Tables 3 and 4 and is discussed below.

Table 2: Main Regression Results

	Dam-only	Dam+Price-only	Base	+Signs	+Targets
	Per capita use (ln)	Per capita use (ln)	Per capita use (ln)	Per capita use (ln)	Per capita use (ln)
Dam level in %	0.0114***	0.00692***	0.00553***	0.00646***	0.00451***
	(8.85)	(8.42)	(4.45)	(4.00)	(2.8)
Marginal cost (ln)		-0.274***	-0.200***	-0.162***	-0.150***
		(-18.80)	(-5.72)	(-3.99)	(-3.80)
Marginal cost low users(ln)		-0.346***	-0.272***	-0.250***	-0.191***
		(-11.02)	(-5.32)	(-4.83)	(-3.69)
Stage 1 restrictions			0.0710*	0.0664	-0.0194
			(1.73)	(1.54)	(-0.47)
Stage 2 restrictions			0.114***	0.120***	0.0923***
			(4.60)	(4.81)	(3.42)
Summer exemption			-0.0383	-0.0359	-0.0122
			(-1.52)	(-1.42)	(-0.48)
Spring clean			-0.0367	-0.0317	-0.0207
			(-1.20)	(-1.06)	(-0.75)
Roadside signs				-0.0301	-0.0217
				(-1.33)	(-1.01)
Water use target (ln)					0.404***
					-4.13
Observations	1539	1539	1539	1539	1539
Adjusted R2	0.77	0.882	0.886	0.887	0.89

Notes: t statistics in parentheses: * p < 0.1, ** p < 0.05, *** p < 0.01. Standard errors are heteroskedasticity and autocorrelation consistent (Newey-West). (ln) indicates a variable that enters in logarithmic specification. ML stands for megaliters. Each regression contains month and day of the week dummies and the complete set of weather controls described in Section 2.

had a large effect of around 14%, they did not differentiate *different* restriction levels in their reported regressions as they found no significant difference in their impacts. One possible explanation for both our results and those of Grafton and Ward is that restrictions largely work by indicating a need for conservation and raising people's expectations that other consumers are making an effort to conserve. This explanation is supported by recent research by the Sydney Water Corporation which concluded that approximately half of the residential water savings during the restrictions was from (unrestricted) indoor usage reductions Beatty

(2011). It is also consistent with studies which find low estimates of willingness to pay for the removal of mandatory restrictions (Hensher et al., 2006; Gordon et al., 2001).

In light of the amount of attention that the economic literature on demand management has paid to the estimation of price elasticities, our first robustness checks are dedicated to this issue. There is ongoing debate in the literature as to whether consumers actually respond to average or marginal cost of utilities (Shin, 1985; Nieswiadomy and Molina, 1991; Arbués et al., 2003; Olmstead et al., 2007). Additionally, since we are using aggregate data, arguments could be made for the use of either 'average marginal cost' or 'marginal cost faced by the average user'. Table 3 shows that although the estimated price elasticities themselves vary substantially according to the specification of price in the regression, the coefficient on dam level is robust. Interestingly, and somewhat reassuringly, the average price elasticity of -0.50 (in column 3) is very close to the implied total price elasticity of -0.47 from our base regression.

Table 4 displays the results of our non-price related robustness checks. Column 1 reproduces our base regression for ease of comparison. Column 2 tests robustness to the inclusion of a time trend to account for any underlying, exogenous technical or behavior trends toward lower consumption. The time trend is statistically insignificant and there is negligible change in any of the coefficients except for an increase in price elasticity. Column 3 adds a lagged dependent variable directly addressing the observed serial correlation evident in the errors. Though the coefficients change, the implied long-run effects of all our coefficients of interest are consistent with our base results.[21] In column 4 we restrict the sample to the Stage 3 restriction period, thereby excluding the initial rapid decrease in both dam level and consumption at the start of our sample. Once again the coefficients are robust suggesting that our result is not driven by the strong correlation between consumption and dam level in the first half of the sample.

The final column of Table 4 makes our base regression consistent with the existing literature on residential water demand-management by excluding dam level. Given that we have shown that dam level has both a direct effect (on voluntary conservation) and indirect effect (through affecting the choice of demand management policies), we would expect excluding dam level to cause substantial bias for the demand-management variables. The results in Table 4 confirm this, and also show that the direction of bias is difficult to predict.

[21] The variable coefficients in the regression of column 4 represent the short-run same period effect. To get the comparable long-run effect of a variable we need to divide the coefficient by (1 - lagged dependent variable coefficient). So the long-run effect of dam levels in the distributed lag model of column 4 is 0.00255/(1-0.545)=0.0056.

Table 3: Robustness to price measure

	Base	MC average user	AC average user	Average MC
	Per capita use (ln)	Per capita use (ln)	Per capita use (ln)	Per capita use (ln)
Dam level in %	0.00553***	0.00500***	0.00550***	0.00674***
	(4.45)	(4.34)	(4.64)	(4.99)
Marginal cost (ln)	-0.200***	-0.121***		
	(-5.72)	(-4.62)		
Marginal cost low users(ln)	-0.272***			
	(-5.32)			
Average cost (ln)			-0.507***	
			(-5.98)	
Average marginal cost (ln)				-0.336***
				(-5.54)
Stage 1 restrictions	0.0710*	0.169***	0.0781**	0.0783*
	(1.73)	(5.82)	(2.00)	(1.90)
Stage 2 restrictions	0.114***	0.151***	0.121***	0.116***
	(4.60)	(6.55)	(5.04)	(4.64)
Summer exemption	-0.0383	-0.0497*	-0.036	-0.0391
	(-1.52)	(-1.79)	(-1.40)	(-1.52)
Spring clean	-0.0367	-0.0261	-0.0294	-0.0328
	(-1.20)	(-0.92)	(-0.98)	(-1.13)
Observations	1539	1539	1539	1539
Adjusted R2	0.886	0.879	0.886	0.884

Notes: t statistics in parentheses: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors are heteroskedasticity and autocorrelation consistent (Newey-West). (ln) indicates a variable that enters in logarithmic specification. ML stands for megaliters. Each regression contains month and day of the week dummies and the complete set of weather controls described in Section 2.

The price elasticity on the marginal cost for the average consumer almost halves, leaving it less than half the elasticity estimated for the marginal cost faced by the low-end users. Meanwhile the summer exemption becomes significant with the wrong sign[22] and the impact of Stage 1 restrictions (compared to Stage 3) becomes large and significant. This final result is consistent with our hypothesis that dam levels and restrictions mutually re-enforce each other. Both convey the message that there is a real water-scarcity issue, and low dam levels encourage compliance with 'mandatory' restrictions which are in realitiy not enforced by either the government or the utility.

[22] The summer exemption briefly relaxes some of the outdoor use restrictions.

Table 4: Robustness Checks

	Base	Time trend	Lagged usage	Split sample	No Dam
	Per capita use (ln)	Per capita use (ln)	Per capita use (ln)	Per capita use (ln)	Per capita use (ln)
Dam level in %	0.00553***	0.00536***	0.00255***	0.00513***	
	(4.45)	(4.27)	(3.91)	(2.80)	
Marginal cost (ln)	-0.200***	-0.282***	-0.0899***	-0.176***	-0.112***
	(-5.72)	(-4.50)	(-4.92)	(-3.05)	(-3.88)
Marginal cost low users(ln)	-0.272***	-0.296***	-0.128***	-0.217***	-0.252***
	(-5.32)	(-5.61)	(-4.76)	(-2.65)	(-4.86)
Stage 1 restrictions	0.0710*	0.0723*	0.0323		0.179***
	(1.73)	(1.77)	(1.54)		(6.14)
Stage 2 restrictions	0.114***	0.116***	0.0494***		0.119***
	(4.60)	(4.73)	(2.73)		(4.68)
Summer exemption	-0.0383	-0.0387	-0.0212	-0.0355	-0.0660**
	(-1.52)	(-1.53)	(-1.33)	(-1.18)	(-2.57)
Spring clean	-0.0367	-0.038	-0.0225	-0.032	-0.0265
	(-1.20)	(-1.34)	(-1.07)	(-0.94)	(-0.84)
Time trend		0.0000626			
		(1.50)			
Lagged dependent variable			0.545***		
			(20.16)		
Observations	1539	1539	1539	1163	1539
Adjusted R2	0.886	0.887	0.917	0.825	0.881

Notes: t statistics in parentheses:* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors are heteroskedasticity and autocorrelation consistent (Newey-West). (ln) indicates a variable that enters in logarithmic specification. ML stands for megaliters. Each regression contains month and day of the week dummies and the complete set of weather controls described in Section 2.

5 Conclusion

Our results suggest both that the extent of voluntary water conservation by residential users can be substantial, and that it is responsive to an objective measure of supply scarcity. As such, this paper provides real-world evidence which supports the common assumption in models of common-pool resource (and public good) cooperation, that voluntary actions are increasing in the social need for (or benefit of) cooperation. It is possible, however, that these results will be difficult to reproduce in other settings. Water is the quintessential 'common pool' resource. Water-storage information has a number of characteristics which render it particularly likely to be useful for eliciting public response. In particular, we note that water-storage information is undisputed, it is a single, objective measure, and it has a clear and easy to understand link to the social problem. Similarly the residents in our study area have characteristics which make them particularly amenable to water-conservation information campaigns: on average they are highly educated, high income, and high water users. Thus further research is necessary to establish whether a response of voluntary conservation to objective need can be identified for different locations and issues.

The broad policy implication of this paper is that objective, salient information should be considered an important compliment to the increasingly popular norm-based information in public education campaigns. There are also policy implications specific to urban water demand-management. Both mandatory restrictions and information campaigns are standard demand-management responses to drought-induced supply shortages. The economics literature, however, has placed a strong emphasis on the benefits of greater reliance on price for demand management. Mandatory restrictions are generally criticized as highly inefficient, and information campaigns as generally ineffective. Our results suggest a reassessment of both the claims is necessary. On the first point, if a significant proportion of the demand reductions associated with mandatory restrictions are actually due to voluntary (e.g. indoor-use) reductions, then current estimates of the efficiency losses caused by mandatory restrictions are significantly over-estimated. On the second point, it seems implausible that the voluntary conservation we observe in response to low storage levels would have occurred in the absence of an information campaign. Thus our findings support the conclusions of Syme et al. (2000), who note that survey-based studies find information campaigns associated with demand reductions of around 25%, and conclude that the lack of effect identified in econometric studies is due to limitations in their methodology - including the inadequacy of 'information campaign' dummy variables in regressions.

Finally we note that there is a substantial literature and public debate over the 'reframing' of water - which has traditionally been viewed as a right or common property resource - as a privatized, price allocated, commodity.[23] There is also mounting evidence of the importance of norms for voluntary cooperation. Together with our findings that voluntary conservation can be significant in times of drought, these literatures suggest that research is warranted into the potential crowding-out effects of the increasing emphasis on price for demand management.

[23] See for example Bakker (2007); Page (2005).

APPENDIX

Table 5: Details of Water Restrictions

	Stage 1	Stage 2	Stage 3	Summer exemption	Spring clean
Lawns	Restricted times[24], sprinkler allowed	Restricted times, no sprinklers	No	Weekends; sprinklers 7pm-10pm	No
Gardens	Sprinkler: restricted times, trigger nozzle hose, can or bucket: any time	Restricted times; no sprinklers, only trigger nozzle hose, can or bucket	Restricted times, no sprinklers, only trigger nozzle hose, can or bucket	Restricted times, no sprinklers, only trigger nozzle hose, can or bucket	Restricted times, no sprinklers, only trigger nozzle hose, can or bucket
Vehicles	Wash on lawn once a week, only trigger nozzle hose, can or bucket	Wash on lawn once a month, only trigger nozzle hose, can or bucket	No washing except at commercial car wash with recycled water	No washing except at commercial car wash with recycled water	Wash on lawn, only trigger nozzle hose, can or bucket
Fountains	Only if uses recirculated water, refill only with trigger nozzle hose, can or bucket	Must be switched off	Must be switched off	Must be switched off	Must be switched off
Ponds	May only be topped up with trigger nozzle hose, can or bucket	May only be topped up with trigger nozzle hose, can or bucket	May only be topped up if support fish	May only be topped up if support fish	May only be topped up if support fish
Pools	Filled: no, emptied: no, topped up: yes	Filled: no, emptied: no, topped up: yes	Must not be emptied, filled or topped up	Must not be emptied, filled or topped up	Must not be emptied, filled or topped up
Windows/Buildings	May be washed but not with a hose	No washing unless health hazard	No washing unless health hazard	No washing unless health hazard	May be washed but not with a hose
Paved areas	No washing	No washing	No washing	No washing	Washing permitted

[24] 'Restricted times' refers to 7am-10am and 7pm-10pm on alternate days according to the 'odds and evens' system.

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