Effectiveness of pricing policies on urban water conservation: A quasi-experimental investigation[1]

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Abstract

Residential water demand management using price and non-price measures has gained considerable attention of water utilities around the world over the last few decades to conserve water. The objective of this paper is to explore the effectiveness of different pricing schemes on water conservation. In this study we compare the 'conservation-orientedness' of two pricing schemes, i.e a flat rate pricing scheme and an increasing block rate (IBT) pricing scheme. For this purpose a quasi-experimental method was used involving 150 suburbs in the Brisbane City Council (BCC) in Queensland, Australia for a four-year period, 2005-2008. Our results showed that an IBT pricing scheme was more effective than a uniform pricing scheme for water conservation. The results also supported the proposition that with fixed charges and an IBT, increasing income has a significantly smaller impact on water demand.

Key words: Demand for residential water; quasi-experiment; pricing schemes; price and income elasticity; Australia.

1. Introduction

In recent years, the demand for urban water has been growing in almost all cities in the world due to economic growth and population expansion. With this increasing demand water utilities around the world have used various demand management strategies to conserve water. While traditional methods of education and conservation programs are still in place, rate structures have also been frequently used as a management tool. In particular, in the recent past pricing policies that involve increasing block tariff (IBT) schemes, decreasing block tariff (DBT) schemes have been adopted in preference to uniform pricing schemes.

The literature on urban/residential water demand has proliferated over time with changing scope and emphasis alongside the development of novel econometric techniques. Even though the direct emphasis of these studies is not on water conservation, a larger group of them focus on traditional demand models and its variants that indirectly provide implications for water conservation. In particular, these studies explore the price responsiveness of demand to *price* changes, a measure that can be used to device effective demand management policies to conserve water.[2] Furthermore, the literature has extended into research questions that are directly relevant to water conservation such as examining the impacts of *non-price* tools on water conservation. For example, non-price demand management tools such as water allocations, use restrictions, public education, free quotas were analysed by Nieswiadomy (1992) Dandy et al. (1997) Renwick and Archibald (1998) Renwick and Green (2000) and Gaudin (2006), Kenney et al (2008). On the other hand, studies that compare *price and non-price* measures included Martínez-Espiñeira and Nauges (2004) and Olmstead and Stavins (2009). Olmstead and Stavins (2009) compared price and non-price measures and suggested that price based methods are more cost effective. Furthermore, researchers are interested in

[2] A comprehensive review of such demand studies can be found in Arbues et al 2003.

comparing *various rate structures* to explore the most effective rate structure for water conservation.

The issue of different rate structures on water conservation has been analysed in detail in Nieswiadomy and Cobb (1993). The term coined as 'conservation-orientedness' is measured by the differences in price elasticities in the demand estimations in their study. Their results suggested that an IBT scheme is more 'conservation-oriented' relative to a DBT scheme. As for a typical demand analysis, this study employed non-experimental means to elucidate the nature of water pricing. Stevens et al. (1992) also compared the price elasticity between increasing, flat and decreasing block tariff schemes and concluded that calculated elasticities were not statistically different across the various price specifications.[3] Olmstead et al. (2003) also analysed different rate structures and suggested that the presence of block pricing appears to affect both water demand and price elasticity. Modelling water demand using a piecewise-linear budget constraint created by block pricing, they found that demand is lower among households facing IBT than households facing uniform marginal prices.

Nataraj and Hanemann (2011), on the other hand, exploited a natural experiment - an introduction of a third price block - to explore the demand for water and conservation. In that sense, their study added a quasi- experimental approach to the existing water demand literature whilst other studies typically have used non-experimental methods of utility pricing.[4] This approach

[3] Foster and Beattie (1981), Schefter and David (1985), Nieswiadomy and Molina (1989) and Timmins (2003) have included both increasing and decreasing block schemes to investigate determinants of residential water demand.

[4] Quasi-experiments are not necessarily designed experiments. However, the variation that occurs naturally provides a researcher to test their hypotheses (see, for example, Meyer, 1995). A novel strand of literature that entails laboratory based experimental economics can be found in the water demand literature as well. See, for example, Murphy et al (2000).

is superior to the latter approach as it circumvents the problem of omitted variable bias that arises from unobserved, location specific characteristics in cross sectional data. The longitudinal studies can avoid this problem to a certain extent, however they often fail to control for other factors that change concurrently with prices (Nataraj and Hanemann 2011).

To that end, our study employed quasi-experimental approach to explore the effects of two pricing schemes on residential water demand in order to measure the 'conservation-orientedness' of such policies. Our study is distinct from other studies as the unit of analysis was almost identical in all other aspects, but only differed in the pricing scheme, which is an ideal situation to compare different pricing policies (see, for example, Reynaud et al 2005 and Olmstead et al 2003 for further details).[5] In this regard, our study adds to the literature by addressing the exact nature of the relationship between rate structure changes and residential water demand. Consequently, the present study enables us to empirically identify the most effective scheme of the two rate structures in terms of urban water conservation, an important policy relevant indication that has not been addressed explicitly in the literature.

We obtained data from the Brisbane City Council (BCC), Queensland, Australia, over twelve quarters for the three-year of 2005-2008. An IBT scheme for residential water use was first introduced by the BCC with effect from the third quarter of 2006. This introduction, which is similar to a quasi-experimental setting, is important here to compare the effectiveness of the two pricing schemes. Therefore, we could consider data recorded for the first six quarters of this period

[5] We have included several control variables to isolate other factors that change concurrently with prices and rate structures.

under a flat rate scheme and data recorded for the next ten quarters under an IBT scheme to test our first hypothesis of the 'conservation-orientedness' of the two pricing schemes.

The rest of the paper is organized as follows: The next section describes the data and methodology used in the econometric estimation of the models. Section three presents the results and section four discusses the implications of the results and concludes the paper.

3. Data and Methodology

For this study we used quarterly data from approximately 153 suburbs from the Brisbane City Council (BCC) in Queensland, Australia for a four-year period, 2005-2008. Brisbane is located on the eastern coast of Australia with a population of approximately 1.8 million in 2014. The water services during this period were provided by the BCC to all the 153 suburbs selected for the study. In the third quarter of 2006 the BCC introduced a three-tiered pricing scheme for water users. Until then, each kilolitre of water for households was priced at AUD 0.89 with a water access charge of AUD 27.50 per quarter. The marginal prices applied in the third quarter of 2006 were AUD 0.91, AUD 0.95, AUD 1.20 for the first 50 kilolitres (KL), 51-75 KL and above 76 KL respectively. In addition, this scheme included an AUD 0.05 water surcharge for every KL used and an AUD 28.25 water access charge per quarter. These rates have changed every year since the tiered pricing scheme was introduced in the second half of 2006. Table 1 summarizes the changes in water rates under an IBT during the study period. One notable observed change was the introduction of the state government bulk water charges in July 2008. This charge was applied for each KL consumed.

Hence, it can be considered that the price of each tier rate increased. This was taken into account in the study by adding the state government bulk water charge to the tier rate system.

Table 1: Water rates during the study period, 2005-2008.

Types of charges	**Before July 1, 2006** **$ per KL**	**July 1, 2006 – June 30, 2007** **$ per KL**	**July 1, 2007 – June 30, 2008** **$ per KL (% change)**	**July 1, 2008 – Dec 31, 2008** **$ per KL (% change)**
Tariff under flat rate	**0.89**	-	-	-
Tier 1		0.91	1.19 (30.76)	0.59 (27.73)
Tier 2		0.94	1.23 (30.85)	0.63 (26.82)
Tier 3		1.20	1.69 (40.83)	1.12 (21.31)
State Gov bulk water charge		-	-	0.93
Water access charge ($ per quarter)	27.50	28.25	35.00 (23.89)	37.03 (5.80)

Note:-The State Government bulk water charge for each KL has been added to each tier rate to estimate the percentage change of water charges.

We consider the policy changes in water charges from a flat rate to a block rate as a quasi-experiment. This is because this policy change allows us to analyze the demand for water under two pricing schemes in which the other determinants for demand for water are controlled.

We examined whether an IBT scheme encouraged water conservation. The treatment group in this experiment was the introduction of an IBT scheme while the control group was the uniform pricing scheme. Because we were interested in investigating the treatment effect of this experiment it was hypothesized that if an IBT scheme was 'conservation-oriented', domestic water consumption of the average household should decline with the new pricing policy. To empirically test this, we conducted a simple regression analysis using the water consumption per quarter of the average household (Q_{it}) in each suburb as the dependent variable[6]. We employed a dummy variable to represent the two pricing schemes (0 = uniform pricing schemes, and 1= IBT). From each suburb we selected the average household's water consumption over sixteen quarters: from the first quarter of 2005 to the fourth quarter of 2008. The following model specification enabled us to compare the situation with households with a uniform pricing regime and those with an IBT. Our model (hereafter Equation 1) was specified as follows:

$$Q_{it} = \beta_0 + \beta_1 Tr_{it} + \beta_2 AP_{it} + \beta_3 HI_{it} + \beta_4 HS_{it} + \beta_5 D_t + \beta_6 Rt_{it} + u_{it} \qquad (1)$$

where:

Q_{it} Average household water consumption of i^th^ suburb at quarter, t.

Tr_{it} Dummy variable representing treatments of price in i^{th} suburb in t^{th} quarter (0 = uniform pricing structure and 1 = IBT).

AP_{it} Average price faced by the households in i^{th} suburb in the t^{th} quarter.

HI_{it} Quarterly mean household income in i^{th} suburb in the t^{th} quarter.

HS_{it} Average household size in i^{th} suburb in t^{th} quarter.

D_t Dummy variable to capture the seasonal variation in water consumption. The hot seasons (spring and summer) were coded as 1 and cold seasons (autumn and winter) were coded 0.

Rt_{it} Dummy variable to capture the water restrictions in place.

U_{it} Error term (assumed to have usual properties).

The switch in pricing policy offered households with two changes. The first related to the changes in the average price, while the second related to changes associated with the structure of the pricing scheme. The treatment dummy captured the changes associated with the latter. To isolate the changes associated with average price changes we included the average price (*AP*) in our

[6] Note that this is the average consumption per quarter per average household.

model. This was calculated by dividing the total water bill by the total consumption over a quarter.[7] The average price was the only price specification that was common to both rate structures, and had an economic meaning. We, therefore, used *AP* to represent the price variable across the two regimes. [8]

We also consider other water policy changes made during study period. In particular, we ascribe a dummy variable ($\boldsymbol{Rt_{it}}$) to capture the water restrictions that were in place during 2005 to 2008. The BCC commenced water restrictions in the third quarter of 2005 and has been increasing subsequently to the toughest level in Q4 2007. In the third quarter of 2008 these restrictions were revised, and relaxed (Bureau of Meteorology, 2011). The water restriction dummy corresponds to ($\boldsymbol{Rt_{it}}$) the severity of the restrictions, "0" being no restrictions and 6 being the highest level of restrictions.[9]

To analyse the income effect of the price change on water demand, we included mean household income (*HI*) of the suburb. This data was obtained from the Australian Taxation Office's (ATO) annual publications from 2005-2008. BCC classified households who earned a gross income of AUS$ 88,210 and above per annum as high income earners. According to this classification, in the richest suburb more than 63% of the population were high income earners. On the other hand,

[7] It is possible to include an interaction term (the treatment dummy and AP) to isolate significant differences between the interaction term and the treatment dummy. Since we estimated the FE and RE, this approach was not taken up here.

[8] The price variable in a typical demand models with IBT includes marginal price (Jones and Morris (1984) and Kulshreshtha (1996), however, this approach was considered inappropriate for two due the fact that marginal price under the flat price scheme resembles the tier one consumption under an IBT. Both vectors are equal to zero.

[9] We gathered data on water restrictions from Bureau of Meteorology, 2011. Urban water restrictions (ranking from 1-6) had been in place in BCC from 2005 to 2008. Following the heavy rainfall, construction of water grids and a desalination plant, the water restrictions were revised into high, medium, and low (permanent water conservation measures) in 2008 July. We consider this fact in merging two types of restrictions to construct a dummy variable. The high level of retractions in place after 2008 July until the end of study period was considered as the same severity as level 1 in the previous water restrictions model.

this figure was just above 5% for income earners in the poorest suburb in the study period. This indicated the variation in mean incomes across BCC suburbs.

Based on the availability of data other control variables were included in the analysis. Average household size (HS) was selected to asses any economies of scale associated with the households. This data was obtained from the BCC community profile which was based on the Australian Bureau of statistics household survey data (BCC 2011).

We employed an OLS estimator to estimate conservation-orientedness (Equation 1). First, we estimated the above relationship for the pooled sample. To correct for potential heterogeneity across the observations, we employed a fixed (FE) effects estimator. The Hausman test was used to test the null hypothesis that the random effects (RE) estimator was valid. A Breusch-Pagan test was also used to test for heteroskdasticity.

Furthermore, due to delayed realization of previous consumption, it is common for current consumption to be affected by lagged water consumption. For this reason, we added a lagged water consumption variable (Q_{it-1}) as a regressor and estimated Equation (1) in dynamic panel form. We employed the System GMM estimator of Arellano and Bover (1995) and Blundell and Bond (1998).[10] From an econometric perspective, such estimators are preferred over a FE model since it enables the problem of endogeneity to be addressed. For example, with the BCC if the policy change was made due to recent increased demand, the pricing scheme change was, in fact, not exogenous but was endogenously determined. Such an issue is circumvented in the System GMM

[10] In particular we used Roodman (2009) xtabond2 command of STATA with a two-step estimator.

estimator by eliminating unobserved heterogeneity by taking the first difference of the time variant variables.[11] Thus, these models produce unbiased coefficients. In our models, suburb specific levels of education, migration and HI were treated as endogenous variables instrumented with lagged values of their levels. We also included a seasonal dummy as an exogenous variable in the model.

4. Results and discussion

The results of Equation (1) used to test whether an IBT structure was conservation-oriented are presented in Table 2. As mentioned earlier, we assumed 'uniform pricing policy' as the control variable and an IBT pricing policy as the treatment variable. The results suggested that there was a significant negative effect on the quarterly water consumption by the average household in the suburbs. That is, the shift from uniform pricing to an IBT policy reduced the average water consumption of the suburb. Furthermore, the average price variable reported in Table 2 showed a negative sign suggesting that there was a significant negative effect on the average quarterly water consumption due to price rise. In all models the water restriction dummy is negative and statistically significant at various levels suggesting that water restrictions in place during the study period has lowered water consumption in BCC significantly. In combination, the above three results show that the pricing scheme changes, change in the average price as well as water restrictions significantly lowered water consumption in the BCC suburbs. On average household water consumption per quarter in BCC suburbs was 54.27 KL during the flat rate system while it was 34.46KL under the increasing block rate system. Overall, there had been a reduction approximated to about a 36.5 per cent in water use after the introduction of new rate structure, which can be ascribed to three factors

[11] The residential water pricing choice with endogenous pricing was analysed in Reynaud et al (2005) using a variant of the two-step selection model introduced by Heckman (1979). In their study, the inverse Mills ratio measured the correlation between the error terms of the demand and selection equation. If the two are significantly correlated, estimates of the general specification of the demand function leads to biased coefficients.

listed above. Our results, therefore, does not rule out the fact that IBT structure has been more conservation-oriented than a uniform pricing policy.

The results presented above suggest that there are several factors that are not likely to enhance water conservation. Firstly, in all models except one, the mean income of the households showed a significant positive sign, indicating that water consumers in the higher income category did not necessarily conserve water. It is often cited that higher income through investment in water conservation, devices could assist in water conservation. However, our results did not support this view.

Secondly, our findings showed that a larger average household size led to a significant increase in quarterly water consumption. The estimated coefficients suggested that economies of scale did not appear to occur here to reduce water consumption among consumers living in large households. This result is consistent with the findings of Dahan and Nisan (2007). However, it is interesting to note that the season dummy was highly significant and had a negative link between water consumption and the season. This might be due to rainfall patterns in Brisbane. Brisbane receives more rain during the summer period, in particular during October – March. Domestic water is used for gardening / lawn maintenance in Brisbane suburbs thus during the wet summer water usage is likely to decrease as less water is now used for lawns[12].

[12]Our sample includes houses (free standing) and not units. These households used water supplied by the BCC to water their gardens. Thus, it is possible to see an increase in water use during dry periods.

Ta**ble 2**: Results of the regressions for the estimation of ‘conservation-orientedness’ of pricing structures.

Variable	**Model I OLS**	**Model II FE**	**Model III RE**	**Model IV OLS**	**Model V FE**	**Model VI RE**	**Model VII GMM**
Tr_{it}	-1.196	-5.865	-3.733	-3.819	3.597	-4.734	-3.372
	-1.92	(7.86)**	(4.71)**	(6.44)**	(3.41)**	(6.16)**	(6.78)**
AP_{it}	-19.834	-14.23	-16.802	-18.173	-6.703	-16.35	-4.261
	(29.39)**	(22.27)**	(25.05)**	(26.49)**	(7.57)**	(26.23)**	(7.01)**
D_t	-0.848	-0.953	-0.906	-0.916	-1.015	-0.946	-0.724
	-1.73	(2.31)*	(2.04)*	(2.15)*	(2.72)**	(2.35)*	(3.14)**
HS_{it}	13.043	9.585	13.601	10.032	16.256	10.201	7.33
	(17.23)**	(2.19)*	(14.80)**	(13.25)**	(4.14)**	(11.95)**	(8.47)**
Rt_{it}	-1.872	-1.573	-1.71	-1.54	-1.944	-1.486	-0.357
	(18.78)**	(12.95)**	(13.14)**	(18.15)**	(16.40)**	(12.47)**	(8.58)**
HI_{it}				0.001	-0.007	0.001	0.001
				(8.29)**	(10.14)**	(5.93)**	(3.03)**
Q_{it-1}							0.579
							(22.69)**
C	52.466	52.874	46.455	42.424	82.771	41.765	
	(34.50)**	(4.69)**	(16.87)**	(18.85)**	(7.85)**	(14.08)**	
R2	0.56	0.55		0.58	0.6		
			H:-155.09			H:124.30	AR1: -3.86
						(0.0000)	(0.000)
			B-P: 1297.29			B-P: 517.95	AR2: 1.12
			(0.000)			(0.000)	(0.264)

Note: The dependant variable is the average water consumption per quarter (Q_{it}); *** significant at 1%; ** significant at 5%; * significant at all 10%; Numbers in parenthesis are p-value. Ɛp = price elasticity; Ɛi = income elasticity;H= Hausman test AR1 and AR2 = Arellano-Bond test statistics for test respectively for AR(1) and AR(2) in first differences; B-P = the Breusch-Pagan test of hereroskdasticity,

5. Conclusions

This paper explored the effectiveness of two pricing structures on water and conservation. We empirically tested this by using a set of panel data for residents living within the BCC, Queensland, Australia. The analysis included all 16 quarters of the four-year period of 2005-2008. Our hypothesis was that an IBT pricing structure is more effective in reducing water demand relative to a uniform pricing structure. Our data showed that on average, there was an approximately 30% per cent reduction in water consumption by moving from a flat rate scheme to an IBT scheme. This reduction was likely to be due to the combined effect of the average price, pricing scheme changes and water restrictions in place during the period. The results suggest that moving to an IBT offers a significant negative effect on water consumption, suggesting that an IBT structure was more 'conservation-oriented' than a uniform pricing policy.

In conclusion, the results of study supported the IBT scheme as more effective in reducing the demand for water than a uniform pricing scheme. While the results are consistent with economic theory and other studies, the novelty in this study is that we have used a quasi-experiment which had not been attempted in previous studies.

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