AGU ADVANCING EARTH AND SPACE SCIENCES

Water Resources Research

RESEARCH ARTICLE
10.1029/2022WR033508

Key Points:

- We estimate the residential water demand and its price elasticity under systematic shifts between uniform price and increasing-block tariff structure
- We estimate different treatments of the sample: splitting it between summer and nonsummer months and between low and high consumption levels
- From a policy perspective, we find that people react to tariff changes and that tariff reforms should consider consumers' heterogeneity

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Citation:
Chovar Vera, A. M., Vásquez-Lavín, F. A., & Ponce Oliva, R. (2024). Estimating residential water demand under systematic shifts between uniform price (UP) and increasing block tariffs (IBT). *Water Resources Research*, *60*, e2022WR033508. https://doi.org/10.1029/2022WR033508

Received 18 AUG 2022
Accepted 15 MAR 2024

Estimating Residential Water Demand Under Systematic Shifts Between Uniform Price (UP) and Increasing Block Tariffs (IBT)

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Abstract We evaluate whether changing from a uniform price (UP) to an increasing block tariff (IBT) changes people's behavior. We exploit a unique setting in which the price scheme moves back and forth yearly from UP to IBT. We discuss the effectiveness of IBT in reducing summer consumption. This issue is relevant to many countries and policymakers interested in designing tariff structures. There is no evidence of how the same consumer may react to systematically switching from one tariff structure to another yearly. We estimate the residential water demand and its price elasticity using a generalized least squared random effect model for the UP and the discrete/continuous choice model for the IBT. In addition, we split the sample between low and high-consumption groups. For the low consumption group unaffected by the tariff change, the elasticity in the nonsummer months is higher (more elastic) than in the summer. Consumers in this group reduce their elasticity from nonsummer to summer months (−0.299 vs. −0.071, respectively) and increase their consumption by 13%. The high consumption group increased its summer consumption, but only by 8.7%, and contrary to the first group, its elasticity increased significantly (from −0.299 to −0.568). The high-consumption group is indeed affected by the change in tariff. From a policy perspective, this implies that the IBT structure is relevant. However, if the policy seeks to promote conservation, it needs to be adjusted to a lower decile of the water consumption distribution to affect a more significant portion of the population.

1. Introduction

We evaluate whether changing from a uniform price (UP) to an increasing block tariff (IBT) changes people's behavior. We exploit a unique setting in which the price scheme moves back and forth from UP to IBT every year. To reach this goal, we estimate the residential water demand and the price elasticity in each period (summer months with IBT and nonsummer months with UP). We also split the sample between low and high-consumption groups and between summer and nonsummer to evaluate the effectiveness of IBT in promoting water conservation.

There are multiple reasons why having accurate estimates of residential water demand is necessary. For instance, knowing the factors behind demand is essential to rate design and predict future demand scenarios. Furthermore, estimating the price elasticity of demand is also relevant to evaluating policies focused on water consumption reduction (Baerenklau et al., 2014; Beecher & Kalmbach, 2013; Renzetti et al., 2015; Sahin et al., 2017). Moreover, price elasticities contribute to evaluating consumer welfare changes (Hajispyrou et al., 2002) due to variations in rates and rate structures (Smith & Al-Maskati, 2007; Thrikawala et al., 2008), and they are relevant to assessing the achievement of multiple tariff objectives (Clarke et al., 2017; Favre & Montginoul, 2018; Zetland & Gasson, 2013). Recently, the adverse effects of climate change on water availability and the constant population growth have motivated a strong resurgence of interest in water demand estimation to contribute to the efficient and sustainable use of water (Nachtnebel & Nandalal, 2021).

The literature regarding residential water demand and price elasticity is extensive. Fortunately, it has been summarized in a series of metanalyses covering econometric approaches, functional forms, price and income elasticities, among other topics (Arbués et al., 2003; Dalhuisen et al., 2003; Espey et al., 1997; Marzano et al., 2018; Nauges & Whittington, 2009; Sebri, 2014; Worthington & Hoffman, 2008). Therefore, we focus exclusively on the residential water demand estimation literature with nonlinear tariff structure (IBT). This literature is more limited, concentrating on applications after Hewitt and Hanemann (1995) suggested the structural Discrete/Continuous Choice model (DCC) for the IBT. The documents relevant to our work are in Table A1 of the Annex. This table shows scarce evidence regarding price elasticity under nonlinear tariff structures. Even more, there is no evidence of how the same consumer may react to systematically switching from one tariff structure to another yearly. Unlike previous literature, our data set presents the advantage of evaluating the consumption behavior as a "yearly natural experiment" because each household is observed when facing an IBT during the summer months and a UP tariff the rest of the year; this situation occurs every year. To our knowledge, this type of data set is unique in the literature.

We use data from a city in Chile, a median-income country. For this group of countries, there is a critical lack of water price elasticities estimations (Fuente, 2019). Having price elasticities estimations for these countries is needed since the evidence shows that the demand estimates respond to the regional contexts (Sebri, 2014). In addition, our case study is also relevant since the country has significant drought problems, although these problems have not yet affected residential water consumption. Furthermore, the fact that the water bill represents a small part of the average family income could be a factor that generates non-conservation-oriented consumption. For decades, the authority has sought to encourage efficient household water consumption through a policy of additional charges for overconsumption in the summer months. Every year, the authority implements a two-tier increasing block system during summer to avoid an excessive increase in water consumption in the months of the highest temperatures. This policy is publicly announced when the summer starts.

We estimate two sets of models. The first uses the complete distribution of households. It includes four water demand models to evaluate whether price elasticity estimates of demand are affected by using different price structures and (or) different methodologies. The results show different elasticities according to the rate that households are facing. In line with the literature, the lowest elasticity is when the UP tariff operates, with a coefficient estimate of −0.146. In the months under the IBT structure, the price elasticity estimated with the DCC model is −0.67. The second set of models looks deep into evaluating the overconsumption price policy. We identify the low-level consumption households and the high-level consumption households. The first group never faces the IBT structure; this group, therefore, behaves as if UP runs all year with an elasticity of −0.071. On the contrary, the second group acts according to the IBT structure since they are very likely to face the overconsumption charge (elasticity of −0.568). As expected, this second group is affected by the price policy.

The differences in elasticities are likely to respond to behavioral reasons since our estimation came from the same group of households observed under different price schemes. Under UP or IBT, the consumers' reaction is price-inelastic, but households were more sensitive under IBT. This increased sensitivity is likely related, among other factors, to the fact that the overconsumption policy has been applied for decades in the Region, and, more importantly, its implementation is accompanied by great dissemination in the media weeks in advance to prepare the population. Therefore, it is plausible that consumers know their application and are aware of the eventual price increase if they increase their consumption.

Our results mainly show that the IBT structure significantly affects those individuals in the upper tail of consumption. Households with low-level consumption reduce their price elasticity from nonsummer to summer months and increase their consumption by 13%. The high-level consumption group increased its consumption in summer months by 8.7% on average, and its elasticity increased significantly from nonsummer to summer.

The paper is organized as follows. In the next section, we present the related literature. Then, in Section 3, our case study's background illustrates the main characteristics of the tariff system and our analysis strategy. Section 4 give details of our empirical strategy to estimate residential water demand under different treatment of our data. Section 5 details the data used in this study, and Section 6 presents the results and their discussion. Finally, in Section 7, we present the conclusions of the paper.

2. Related Literature

Estimating price elasticities under different tariff structures, including nonlinear ones, has important policy implications, mainly in the design of water-pricing schemes. Academics, authorities, and water utility managers try to predict the impact of different tariff structures on water consumption and multiple opposite tariff goals (Fuente, 2019; Klassert et al., 2018; Leflaive & Hjort, 2020; Nauges & Whittington, 2017; Renzetti et al., 2015;

Rinaudo et al., 2012; Smith & Al-Maskati, 2007; Thrikawala et al., 2008). Authors use the estimated parameters of water demand functions and the price elasticity of demand as inputs in their evaluations; therefore, they need reliable estimates that consider the nonlinearities of the rates. Furthermore, using nonlinear structures, particularly IBT, has become common worldwide (Leflaive & Hjort, 2020; Whittington & Nauges, 2020).

Table A1 (see Appendix A) collects the literature most closely related to our paper. Although every article estimates the residential water demand, their contributions differ from ours in the data set and (or) the methodology used to evaluate residential demand under a nonlinear tariff structure. Furthermore, none of these articles report systematic rate changes like ours. The table also shows the goals, the data characteristics, and the estimation strategy. Similar to our paper, a few articles compare different estimation methodologies (including the DCC model) to estimate water demand and price elasticities under different rate structures (Baerenklau et al., 2014; Olmstead, 2009; Olmstead et al., 2007). However, their data sets are formed by split samples: different groups for different price structures, one under UP and the other under IBT (Olmstead, 2009; Olmstead et al., 2007). In another case, although the population under study is the same, they compare different periods with different tariff structures (using different estimations approaches), the first period under UP and then IBT (Baerenklau et al., 2014). Some authors have also considered the nonlinearities using aggregated data; for example, Sebri (2013) used a DCC approach, taking the proportion of households in each block to estimate the effect of average price on water consumption. However, new evidence suggests that the estimation of the elasticities is influenced by the data's aggregation level (Flores Arévalo et al., 2021). Indeed, data quality is essential in studying water demand under nonlinear prices. It is desired to have complete information on price structure and level of consumption. Less comprehensive data sets, such as surveys, cannot model the rate structure, and authors must use average prices (Grafton et al., 2011).

The DCC model estimation has advantages regarding post-estimation economic analysis over nonstructural estimation approaches, such as the reduced-forms IV model (Olmstead, 2009). In an IBT setting, the estimation of price elasticities should consider different potential situations. For instance, let us consider a simple case of two blocks, where price changes can mean changes in the first block price, changes in the second block price, or simultaneous changes in both prices. Thus, consumers may move their consumption from one block to another, from a block to a switching point, or reverse. The DCC model of two errors permits the analysis of any of these changes but not the reduced-form approaches. In addition, the DCC model allows welfare analysis by recovering the structural parameters of the consumer's utility function (Szabó, 2015). Apart from the reduced-form and DCC models, other approaches have been used to estimate water demand functions, such as the Stone-Geary model (Clarke et al., 2017) or the deductive model (Rosenberg, 2010).

Another important point is that the literature reports differences in price elasticities magnitudes between regression models and the structural DCC model. The DCC's utilization in the water demand estimation under IBT structures has shown higher price elasticity than other regression approaches (Dalhuisen et al., 2003; Hewitt & Hanemann, 1995; Olmstead, 2009; Olmstead et al., 2007; Sebri, 2013; Szabó, 2015), with some exception (Baerenklau et al., 2014). Part of these differences in magnitudes is attributable to the price structure (Espey et al., 1997). These differences are also expected because these price elasticities are estimated under different modeling frameworks. Under the DCC model, price elasticity is a function that includes the probabilities of being in each kink point segment and the income effect that the change price generates. Moreover, the evidence suggests that factors such as climate issues, pro-conservation attitudes (Hassell & Cary, 2007; Maas et al., 2017; Willis et al., 2011), seasonality, and tariff structure systems (Baerenklau et al., 2014) may help to understand differences in price elasticities under UP and IBT. Olmstead (2009) suggested their differences in elasticities are due to the underlying heterogeneity among utilities adopting different price structures. Yet, they also mention it could be a behavioral response to price structure.

In addition, it is important to remember that the DCC model assumes people respond to marginal prices instead of average prices. According to Cook and Brent (2021), there are cases in which people react to marginal prices (Ito & Zhang, 2020; Nataraj & Hanemann, 2011), while in others, they react to average prices (Ito, 2014; Nieswiadomy & Molina, 1991; Shin, 1985). Gibbs (1978) points out that the correct price variable in water residential demand models is the marginal price since the average price generates an overestimated consumption response to price and income changes. This is a pattern in the literature. Dalhuisen et al. (2003), Espey et al. (1997), and Sebri (2014) found that the elasticities using average prices are higher in absolute value than elasticities using marginal prices. Furthermore, Nieswiadomy and Molina (1991) show that the

Table 1
Monthly Water Bill Faced by the Consumer

Period	Bill scheme	
Summer months	$\text{Bill}_i = \begin{cases} \text{FC} + p_1 \times Q_i & \text{if } Q_i \leq w \\ \text{FC} + p_1 \times w + p_2(Q_i - w) & \text{if } Q_i > w \end{cases}$	(1)
Nonsummer months	$\text{Bill}_i = \text{FC} + p_1 \times Q_i$	(2)

reaction to marginal or average prices depends on whether the tariff structure is decreasing or increasing. Luo et al. (2022) found that higher-usage consumers respond more to average prices, whereas lower-usage consumers respond more to marginal prices. In our opinion, the discussion is still open and context-dependent. Cook and Brent (2021) argue that the consumers' response to marginal prices depends on the information and complexity of the tariff structure.

Finally, the literature also shows evidence of how heterogeneity in household consumption patterns or the final use of water affects the magnitudes of the price elasticity of demand. Mansur and Olmstead (2012) identified water demand according to final use, indoor and outdoor, and they concluded that outdoor consumption is more elastic than indoor. Considering the level of consumption of households, El-Khattabi et al. (2021) conclude that households with a higher level of consumption are more sensitive to price changes than those with a low level of consumption. In the same direction, Wichman (2014) found higher average price elasticity for households with higher consumption levels.

3. Background of Case Study

The province under study is one of the four provinces forming the Biobio region in Chile, a middle-income country in South America. In the country, the drinking water and sewage system operates under government regulation through the "Superintendency of Sanitary Services" (SISS), and the services of production and distribution of drinking water and collection and disposal of wastewater are mostly concessioned to private companies.

At the national level, the tariffs of residential water are determined by decree every 5 years in an iterative process in which both the concessionaire companies and the SISS participate. The process begins with the proposal by the SISS to the Ministry of Economy of the maximum tariffs that the companies can charge their clients. The prices are determined according to the different steps of producing and distributing drinking water, collecting wastewater, and disposing and treating wastewater, considering the costs of every system. A system refers to a set of facilities that can be interacted with, associated with each stage of the services, which are considered as a whole to minimize the long-term costs of providing the service. As the tariff management for each system is very complex, companies define tariff groups according to the similarity of costs.

Under this frame, the consumer faces a tariff scheme comprising two tariff structures in the year. During the summer, the price includes a fixed charge plus a per-unit variable part consisting of a tariff of two increasing blocks. The second block, the overconsumption block, starts at 40 cubic meters (m^3) or higher (the norm says that the block begins at 40 m^3 of consumption or the level of average non-peak months' consumption if this is higher than 40 m^3). For the rest of the year, the tariff structure has a fixed charge plus a per-unit variable part, which consists of a UP. The following equations in Table 1 represent the monthly bill for each household:

Where FC is the fixed charge, p_1 is the price for each unit of water consumed measured in cubic meters. In the summer months, this is the marginal price of the first block. p_2 is the overconsumption charge for those consumed units above the w, being w the threshold between the first and the second block.

The province under study is formed by 12 communes (administrative units). These communes belong to two tariff groups; Group 1 comprises nine communes, while Group 2 comprises three communes. Group 2 faces higher marginal prices than Group 1. The chart below (Figure 1) shows the evolution of the variable part of the tariff structure, the average of p1 and p2 (only for the summer months) by each group from 2007 to 2012.

Table 2 shows each commune's residential water consumption level. We observed that the average household consumption in both groups is between 10 and 18 m^3. These average consumption levels show an essential issue regarding the overconsumption policy: only some households, mainly those located in the right tail of the water consumption distribution, may act in response to the overconsumption message and be worried about the policy implementation. Also, it shows that those households that consume around the average level have ample room to increase their consumption since the beginning of the overconsumption block is a very high level of consumption. Therefore, it is necessary to evaluate how these observations relate to the objective set by the authority when seeking to implement this overconsumption block. According to the message that the SISS sends to the

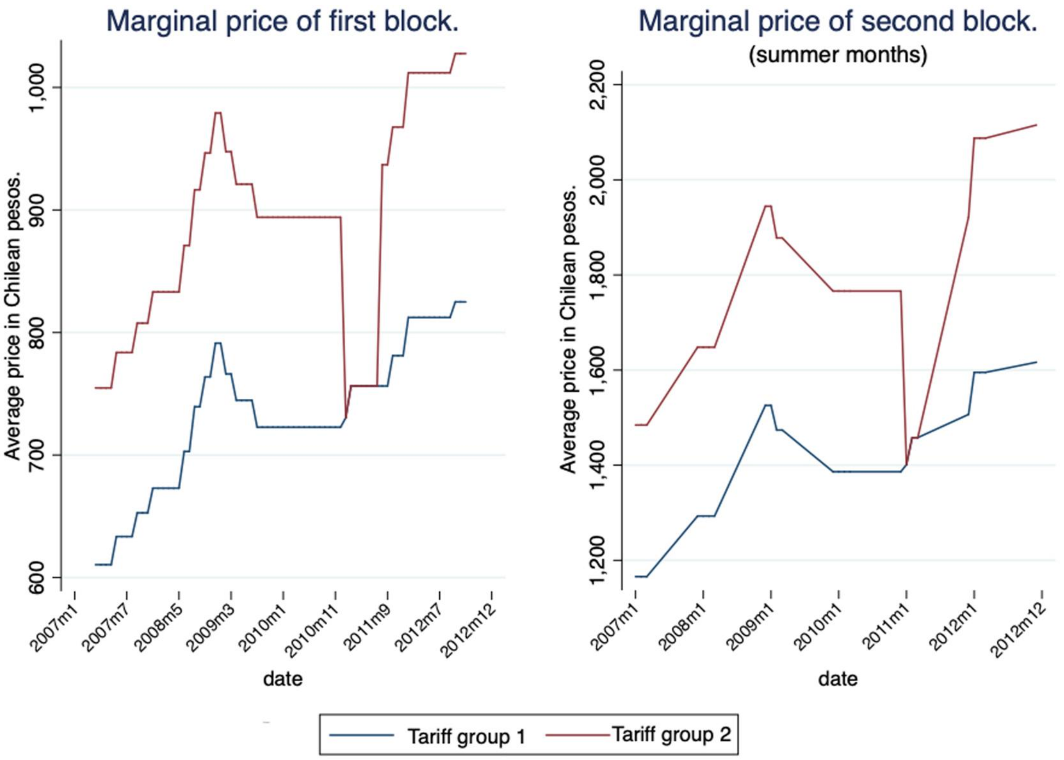

Figure 1. Evolution of water price per tariff group from 2007 to 2012 (nominal prices). Note: The figure shows the average marginal prices of the tariff structures across communes from January 2007 to December 2012. The figure on the left side shows the average marginal price of the first block (p1 in Equations 1 and 2). The figure on the right shows the average marginal price of the second block (p2 in Equation 2), which is present only in the summer months. The blue line is for tariff Group 1, and the red line is for tariff Group 2.

population, this block seeks to encourage the rationalization of water consumption, especially in the face of the drought problems that exist in the country. A relevant question would be: why not design a policy that generates conservation incentives throughout the population?

Table 2
Average Residential Water Consumption in m^3

Commune	Tariff group	Average consumption (m^3) Summer	Nonsummer
Com1	1	17.9	16.7
Com2	1	11.9	10.9
Com3	1	17.0	15.1
Com4	1	11.9	10.8
Com5	1	17.4	15.9
Com6	1	17.3	15.6
Com7	1	16.1	14.8
Com8	1	15.2	13.4
Com9	1	15.4	14.1
Com10	2	12.5	10.8
Com11	2	14.4	12.3
Com12	2	13.3	11.1

The 12 communes of the province share similar weather, precipitation, and temperature levels. However, they are different in population size and socioeconomic characteristics. The communes of Group 1 have a larger population than the communes of Group 2. In the first group, the number of households per commune is between 15 thousand and 85 thousand, while in Group 2, the number of households per commune is between 5 thousand and 9 thousand. On the other hand, the communes of Group 2 have a higher poverty rate (according to the multidimensional poverty indicator), ranging from a percentage of the population in poverty between 22.2% and 37.8%, while in the communes of Group 1, the population in poverty situation goes between 11% and 19%.

We defined our empirical strategy according to the conceptual framework explained in this section. First, we assess how consumers behave when the price follows a simple price structure (UP scheme), where the price is not endogenously determined. The panel model allows us to capture the parameter of interest directly. Second, we move to assess the behavior of consumers under an IBT scheme. In this case, the price is endogenously determined; thus, we use a structural model to correct it, which is the DCC model. We evaluated the well-known IV model as well.

Third, to evaluate consumer behavior under the overconsumption policy applied in the summer months to control the increase in consumption, we split the data into two groups of users: consumers with low levels of consumption and consumers with high levels of consumption. This analysis is relevant given that this overconsumption charge (second block of the IBT setting) starts at 40 m^3 or higher, causing, as we mentioned before, only a small part of the households to be affected by this policy.

Finally, it is important to mention that all our models assume people react to marginal prices instead of average prices. While this is not a problem in the UP case because marginal and average prices are the same, it is controversial in DCC models. Following the literature, in the frame of our case study, this assumption is plausible since the consumer likely knows the tariff system due to mainly three reasons: (a) the overconsumption block has been running in the country for over 20 years; (b) the monthly water bill provides extensive detail of the different charges that are being considered, the level of consumption for the period, and it also shows a graph with the evolution of the level of consumption in the last 13 months. Also relevant is that the consumer receives the water bill every month at home; (c) a month before the overconsumption charge starts, it is announced in the news, newspaper, and television news programs. In addition, we tested whether people react to marginal or average prices using the encompassing test suggested by Ito (2014) and found that both prices generate the wrong sign and are statistically significant. Unlike Ito, we do not observe that the marginal price loses its statistical significance when average prices are included in the regression.

4. Empirical Strategy

Our empirical strategy uses a log-log functional form for the demand function. The Log-log is one of the dominant functional forms used in the literature of residential water demand estimation under the DCC approach (Baerenklau et al., 2014; Hewitt & Hanemann, 1995; Olmstead, 2009; Olmstead et al., 2007). The linear functional form is also typically used; however, it has one important criticism. From a theoretical perspective, the functional form should consider that water is an essential good. However, if the linear form is applied along the demand curve, there will be a price where zero demand will be generated, which is against the idea of a basic good. On the other side, from an empirical perspective, one needs to consider that in the DCC model, each functional form implies a different likelihood function and its intricate calculation of price elasticities (See Olmstead et al., 2007; Vásquez et al., 2017). In this regard, the log-log functional form to estimate the DCC model has shown advantages regarding the goodness of fit. Vásquez et al. (2017) found the lowest akaike information criterion measure of this functional form compared to the linear, semi-log, full-log, and Stone-Geary models. Moreover, using the log-log functional form allows us to compare our results more directly with those in the literature. Thus, our water demand is as follows:

$$\ln(x_{it}) = \delta Z_{it} + \alpha \ln(p_{it}) + \mu \ln(y_{it}) + \eta_i + \epsilon_{it} \tag{3}$$

In Equation 3, the left side is the logarithm of the household's monthly water consumption in the month "t." The right side contains the variables price and income (virtual income when the evaluated structure is the IBT) in logarithm, p and y, respectively, and other explanatory variables included in the matrix Z, which are the number of household members, temperature, precipitation, and a dummy variable to account for the strong earthquake that occurred in the area at the beginning of 2010; this variable takes the value 1 in the earthquake period, and 0 otherwise. The matrix Z also contains commune fixed effects. δ, α, and μ are the unknown parameters of the utility function to be estimated; η is an error term that represents the households' heterogeneous preferences for residential water consumption unobserved, which is time-invariant; and ϵ represents the error in the researcher's perception of household's preferences, which varies over time and across households.

We seek to identify how the rate structure affects the estimation of demand's price elasticity through the analysis of four models applied to different subgroups of the data. The first model is a GLS Random Effects (GLS-RE) for those observations under UP; the second model is a DCC model for those observations under IBT; the third model is again a DCC model, but in comparison with model two, this model includes the entire data set (observations under UP and IBT); and model fourth, is an IV model, that uses only observations under IBT.

The first model, GLS-RE, considers the observations of the nonsummer months, where the uniform rate takes place. Approximately two-thirds of the database corresponds to these months, with 8,338,530 monthly observations. Unlike block price structures, in a UP system, the price and consumption are not co-determined, so correcting for endogeneity is unnecessary. The GLS-RE approach estimate Equation 3 considers the composite error term, $v = \eta + \epsilon$, where η is assumed to capture individual-specific, time-invariant factors affecting the dependent variable but unobserved to the econometrician (similar to the DCC approach described below), while ϵ is the random error. In practice, this approach quasi-mean centers all variables and then applies the standard ordinary least squares (OLS). This implies that the GLS-RE estimator is the weighted average between the between and within regression (for further details of this model, review Wooldridge, 2013, Chapter 14). In addition, to control for heteroskedasticity, we use robust errors.

The second model (DCC—under IBT) considers the water demand estimation using only those months where the increasing block structure is in operation (summer months), corresponding to approximately one-third of the data set (4,134,705 monthly observations). This tariff structure produces that the decision of the consumer regarding water consumption is a mixture of a discrete choice, which is the choice of the block where to consume, and a continuous choice, which corresponds to the quantity of water to consume, producing a co-determination of the marginal price and the amount of water consumed.

The DCC model has gained popularity because it solves the simultaneity problem between the co-determination of the price and the quantity of water consumed. Since its derivation has been widely explained in the literature, we recommend that the interested reader review Hewitt and Hanemann (1995), Olmstead (2009), Olmstead et al. (2007), and Vásquez et al. (2017) for a full derivation of the model. Nevertheless, we provide a short derivation in Appendix B. We estimate the unconditional water demand using the maximum likelihood approach.

The third model (IBT—full sample) corresponds to the water demand estimation using the whole sample, from January 2007 to December 2012, covering consumption for 178,255 households (12,811,852 monthly observations). Since the consumer faces both the UP and IBT structures, the water estimation function combines the two likelihood functions, implying that the structural parameters are identical in both models.

The fourth model is an instrumental variable model for panel data with random effects. This model is in the spirit of the one estimated by Olmstead (2009) and can be considered more similar to the GLS model. The IV approach and the 2SLS were typically used to estimate residential water demand under the IBT rate to deal with the simultaneity problem (Arbués et al., 2003). However, the disadvantages of these approaches are well known: while they directly model water consumption, these methods miss the consideration of the choice of the consumption block. We include this model to compare our results with the literature, particularly Olmstead's conclusions. Thus, we used similar instruments for the price and the virtual income variable: the marginal price of consuming increments of water, p_2, the monthly fixed charge, and the exogenous covariates from the water demand model.

In the previous models, we considered all individuals together regardless of their consumption level. Therefore, to account for the heterogeneity of consumption, we carried out a series of estimations considering the heterogeneity of household consumption. We identify two groups of households according to their position in the tails of consumption distribution. The first group, low-level consumption, comprises households that consume at least 70% of the time in the deciles one to three. In addition, we add the restriction that they never consume more than the median consumption. The second group, high-level consumption, corresponds to households generally consuming between the 8th and 10th deciles and never consuming less than the median. The choice of the deciles under which to take the low-level and the high-level consumption responds to the idea of finding a real control group to evaluate these households that are likely to fall into the second consumption block. This control group never faces the block rate since it never passes the median of consumption. They, in reality, only face a UP throughout the year. The second group is very likely to reach the overconsumption threshold, facing the IBT structure.

Using these two groups, we repeat the models already estimated for the whole population. However, in this part, the analysis is as follows. First, we seek to identify differences in consumption between summer and nonsummer months for the first group. Since they face UP structure during the year, there is no endogeneity problem in determining price and consumption. Thus, the GLS RE is a reasonable estimation option. Second, we estimate the water demand for nonsummer months using the GLS RE model for the second group. We compare it with the previous estimation, evaluating differences in demand between these groups in the months that explicitly face the same rate. Third, we estimate the water demand using the DCC model for the summer months of the second group.

5. Data

Our data set corresponds to an unbalanced panel from 2007 to 2012 containing monthly information about the residential water consumption at the household level, household characteristics at the census-district level (average), income at the commune level (average), and climate variables with variations every 100 m of distance. We have 178,255 households, reaching a total number of 12,811,852 observations. These observations correspond to 12 communes located in the province under study. Table 3 shows the descriptive statistics of water consumption in cubic meters; the average consumption is 15 cubic meters (m^3), and the median is 13 m^3. While consumption increases in the summer (December–March), the differences are not significant. This distinction between summer and nonsummer months is relevant, considering that the rate changes occur on these dates. When summer starts, a two-block tariff structure is implemented, where the second block represents a charge for overconsumption. We will observe what happens through these seasonal changes to meet our objective of estimating the demand for water and its price elasticities. The histogram in Figure 2 shows the distribution of the monthly water consumption of households from 2007 to 2012. From where it is possible to see the concentration of water consumption below 20 cubic meters.

Our primary data set was provided by the Water Utility that supplies urban households of the province under study. The data contains for each household the total consumption of water measured in cubic meters (1 cubic meter = 1,000 L) and the geographical location coordinates, which allows us to identify the commune where the house is located and, even better, to identify the census-district (a smaller unit of observation). In addition, the water utility provided the details of fixed costs and marginal prices valid in each period in each commune. With this information, we calculated the monthly bill paid by each household. The second source of information corresponds to the 2002 population census from which we have household sociodemographic characteristics in the province under analysis. However, we cannot match census information with the water consumption data set at a household level, so we calculated the average of each sociodemographic characteristic at the census-district level, covering 92 census tracts.

The use of aggregated variables at the census-district level has been classic practice in the literature since disaggregated data at the household level is costly to build. Even more, the limitations of disaggregated data at the household level have led to working with higher levels of aggregation both over time and space. In a meta-analysis document, Marzano et al. (2018) found that only 36% of their studies' collections use disaggregated data at the household level. Although disaggregated data is desirable, the combination of water companies' consumption data and census-district information allows for a larger panel, which favors the estimate, as in our case. No studies quantify the bias when using aggregated rather than disaggregated data. Nevertheless, some studies have found that this difference affects price elasticity (Flores Arévalo et al., 2021; Sebri, 2014). However, some studies show the opposite, such as the meta-analysis by Marzano et al. (2018).

The climate variables were obtained through an interpolation process. This climate data set was generated through the project Welfare and Economics Evaluation of Climatic Change Impacts on Water Resources at River Basin, ID 10 69 24-001, 2013–2015 (financed by the International Development Research Center). The data contains monthly averages of maximum temperature, minimum temperature, and precipitation with a variation every 100 m distance. The last source of information is the National Socioeconomic Characterization Survey, CASEN, waves 2006, 2009, and 2011. From here, we obtained the average household income at the commune level.

Table 3
Water Consumption in m^3/Month

	2007–2012	2007–2012 summer months	2007–2012 nonsummer months
Mean	15	15.86	14.58
Std. Dev	10.64	11.11	10.36
Median	13	13.08	12
Minimum	1	1	1
Maximum	100	100	100
No. Observations	12,473,235	4,134,705	8,338,530

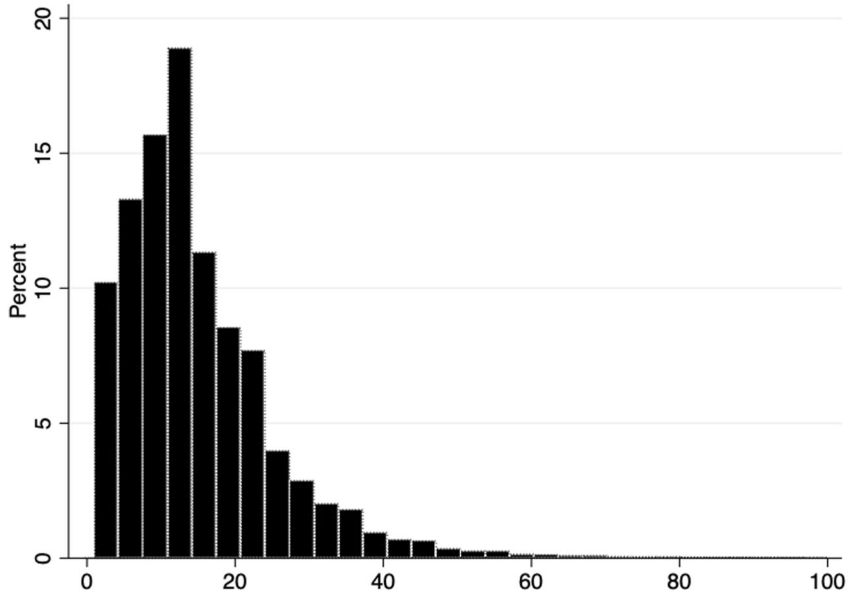

Figure 2. Monthly water consumption distribution from 2007 to 2012 (m^3/month).

The descriptive statistics of the variables used to estimate water demand are presented in Table 4: precipitation, temperature, average members of the household by census-district, and average income by the commune. In addition, Table 5 shows the descriptive statistics of the tariff structure's price.

6. Results and Discussion

Estimating the four different water demand models allows us to evaluate whether the estimates of price elasticities of demand are affected by using distinct price structures and methodologies. Table 6 shows the first round of regression results between summer and nonsummer months. The explanatory variables have the expected signs across the models and maintain statistical significance, but the magnitudes of their parameters are sensitive to the model specification. Only the model second and fourth use the same information (summer months) for the entire population. The IV approach shows these two models' highest parameter values (in absolute terms). However, although the signs of the explanatory variables are as expected, the validation of the instruments used showed that they do not satisfy the necessary conditions for the coefficients to be unbiased (rejecting the null hypothesis of the Sargan-Hausen test of over-identification). Therefore, the interpretation and use of the IV model for estimating water demand in the summer months is ruled out.

Table 4
Descriptive Statistic Variables

	Mean	Standard deviation	Minimum	Maximum
Precipitation (millimeters per month)	85.14	83.4	0	382.79
Maximum temperature °C	18.2	4.14	6.53	31.69
Minimum temperature °C	7.03	2.59	−1.18	17.67
Total monthly bill (Chilean pesos)	15,275	12,523	1,144	207,246
The average number of members of the household by census-district	4.35	0.2	3.36	5.21
Average price nonsummer months (Chilean pesos)	737	63	610	1,027
Marginal price block 1 summer months (Chilean pesos)	735	71	610	1,027
Marginal price block 2 summer months (Chilean pesos)	1,420	151	1,165.75	2,115.14
Fixed charge (Chilean pesos)	595.2	30.8	534	651
Average household income by commune (Chilean pesos)	608,313	170,233	193,421	1,025,133

Table 5
Prices Tariff Structures, 2007–2012

	Summer months	Nonsummer months
Fixed charge	593.28	596.13
P1	735.47	737.17
P2	1,420.27	–
Monthly bill	12,506.45	11,332.87
Switching point	40 m^3	–

Note. Prices are in nominal Chilean pesos. Values correspond to the monthly average over the period.

Climate variables are statistically significant across models. Higher precipitations predict lower water consumption, although their parameter values are near zero. Conversely, higher temperatures indicate higher water consumption according to what is expected. The elasticity is about 0.015, and similar across models.

Household size has a positive influence on water consumption. However, the parameter magnitude changes across models, indicating higher effects during the summer months. This is not surprising since higher temperature increases water use, especially discretional consumption, which larger families enhance. The DCC model estimates a conditional elasticity of 0.081, more elevated than the rest of the year (UP model).

We also include a dummy variable to control for the earthquake that occurred in February 2010, and its effect is negative, as expected, given the widespread destruction in the region. Fixed effects by commune (12 communes) are also included to control for unobserved heterogeneity affecting water consumption. In the case of the DCC model, we report the variances of the error terms, which indicate that the heterogeneity error mainly explains the variation in consumption.

6.1. Price Elasticity of Demand

The price elasticity in the DCC model requires further analysis. The price coefficient represents only the conditional price elasticity (conditional on block location). In contrast, the unconditional elasticity can be estimated through a simulation process taking the estimated demand parameters, as Hewitt and Hanemann (1995) and Olmstead (2009) calculated. It is also possible to estimate the unconditional price elasticity following the analytical expression developed by Olmstead et al. (2007) that considers the change in the expected value when

Table 6
Estimations of Residential Water Demand

	GLS UP months	DCC IBT	DCC Full—Sample	IV model
	Months without overconsumption block	Months with overconsumption block	All months	Months with overconsumption block
Price	−0.146***	−0.665***	−0.496***	−1.191***
	(0.007)	(0.004)	(0.003)	(0.014)
Income	0.024***	0.116***	0.128***	1.285***
	(0.008)	(0.007)	(0.004)	(0.015)
Precipitation	−1.27E−04***	−0.001***	−1.20E−04***	−2.19E−03***
	(2.16E−06)	(3.76E−05)	(3.90E−06)	(2.87E−05)
Temperature	0.015***	0.016***	0.016***	0.013***
	(9.97E−05)	(4.49E−04)	(1.06E−04)	(2.49E−04)
Members of households	0.043***	0.081***	0.055***	0.102***
	(0.009)	(0.002)	(0.001)	(0.009)
Earthquake dummy	−0.108***	−0.272***	−0.151***	−0.319***
	(0.001)	(0.002)	(0.001)	(0.001)
Constant	2.740***	4.795***	3.605***	−7.505***
	(0.098)	(0.088)	(0.044)	(0.132)
σ_η		0.721***	0.715***	
		(4.16E−04)	(3.30E−04)	
σ_ϵ		0.214***	0.197***	
		(0.001)	(0.001)	
Commune fixed effect	YES	YES	YES	YES

Note. Standard errors in parentheses. ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.

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the price structure changes simultaneously by 1% (see Appendix A in Olmstead et al. (2007, p. 194)). Using this approach, we calculated an elasticity of −0.580 (s.e. 0.034) with a confidence interval of [−0.587, −0.574]. This elasticity is lower than the value of the conditional price elasticity reported in Table 6, and it indicates that a simultaneous increase in all tariff prices of 1% generates a decrease in water demand by 0.58%.

Therefore, the lower price elasticity estimate (in absolute value) is observed under the UP months (−0.146), indicating that an increase of 1% in the marginal price produces an increase in the demand of 0.15%. The second model, estimated under DCC, says the conditional price elasticity is −0.665. The entire sample estimation (model 3) shows a conditional price elasticity of −0.496.

The price parameter of the GLS model is in the range reported in the literature. Worthington and Hoffman (2008), in a survey of residential water demand estimations, report price elasticities between 0 and −0.5 for the short run and between −0.5 and −1 for the long run. In a meta-analysis of price elasticities, Espey et al. (1997) reported an average of −0.51 with a median of −0.38 and −0.64, respectively. Also, Sebri (2014) identified 638 price elasticity estimates from −3.054 to −0.002 with a mean of −0.365 and a median of −0.291. In addition, the results showed that compared to OLS estimates, all other estimation techniques tend to report the residential water demand as more price elastic. Although we are in the range, our price elasticity of demand under UP months is lower than the average observed in the literature.

The evidence on residential water demand is scant and scattered regarding price elasticities estimated using the DCC model under IBT. From the literature, we have found a few documents using DCC and reporting price elasticities, and we observe a wide range of price elasticities, going from 0 to −1.63. However, these documents differ in the data set type and the tariff system. Hewitt and Hanemann (1995) were among the first to use this approach for residential water demand and reported higher price elasticities in the interval [−1.57/−1.63]. Their data were observations from June, July, and August (only summer months) under two increasing blocks from Denton, Texas. Using data from urban areas in the United States and Canada, Olmstead (2009) and Olmstead et al. (2007) estimated price elasticities of −0.59 and −0.61, respectively. The tariff structures used to calculate these values comprise different rate structures (two-tier and four-tier). From developing countries, Klassert et al. (2018) and Szabó (2015) found price elasticities in the range of 0 to −1.45. Klassert et al. used data from an arid developing country of Jordan and Szabó from South Africa. In addition, Szabó has a database that consists of a mixture of decreasing and increasing block rates. Thus, our estimations align with those of Olmstead (2009) and Olmstead et al. (2007).

Respecting the IV estimation, our elasticity, −1.191, is in the upper range of values in the literature under this setting. Moreover, in our case, it is higher than the one estimated under the DCC framework, which is the opposite result of Olmstead (2009). She obtained a price parameter of −0.29 under IV versus −0.61 under DCC. Our result is mainly because our coefficients are biased due to incorrect instruments. An important message from this result is that water demand estimates and methodologies are context-dependent. Our model uses the same structure of instruments used in the literature; however, given our tariff structure, it does not deliver reliable results. Theoretically, the IV model solves endogeneity problems consistently, but the main challenge is finding the appropriate instruments. Instead, the DCC approach resolves this problem structurally. According to Olmstead (2009), this critical difference in solving the endogeneity problem does not ensure one model over another. In a comparative exercise, Olmstead (2009) showed that both the DCC and IV models present bias in estimating parameters. However, the bias is more negligible under DCC in the case of the price parameter when the demand variability is explained mainly by households' preferences captured by the heterogeneous error. Olmstead's result cannot be generalized since price elasticity is sensitive to many factors (Dalhuisen et al., 2003; Espey et al., 1997; Flores Arévalo et al., 2021; Sebri, 2013, 2014). Finally, Hewitt and Hanemann (1995), also comparing the DCC and the IV approach, found a positive price parameter but statistically insignificant for the IV estimation.

The simple comparison in the literature between price elasticities under UP and IBT shows differences in magnitudes. Generally, UP elasticities are lower than IBT elasticities; Dalhuisen et al. (2003) and Espey et al. (1997) show evidence suggesting that IBT produces residential water demand that is more price-elastic. In particular, the utilization of the DCC model shows higher elasticities. In line with this evidence, we find that the elasticities of households facing UP during summer months are roughly three times lower than when those facing IBT.

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Table 7
Estimates According to Consumer Groups

	Group 1—low consumption		Group 2—high consumption	
	GLS nonsummer	GLS summer	GLS nonsummer	DCC summer (IBT)
Price	−0.299***	−0.071***	−0.132***	−0.568***
	(0.019)	(0.016)	(0.012)	(0.008)
Income	0.159***	−0.303***	0.008	0.145***
	(0.016)	(0.017)	(0.01)	(0.009)
Precipitation	−9.98E−05***	0.001***	−2.58E−05***	−8.00E−05
	(6.45E−06)	(3.79E−05)	(3.54E−06)	(4.00E−05)
Temperature	0.021***	0.035***	0.017***	0.037***
	(3.00E−04)	(0.001)	(1.84E−04)	(8.20E−04)
Members of households	0.119***	0.142***	0.049***	0.127***
	(0.021)	(0.022)	(0.012)	(0.004)
Earthquake dummy	−0.079***	−0.226***	−0.066***	−0.296***
	(0.003)	(0.004)	(0.002)	(0.004)
Constant	0.476*	4.845***	3.810***	4.100***
	(0.189)	(0.204)	(0.111)	(0.112)
σ_η				0.295***
				(0.001)
σ_ϵ				0.250***
				(0.001)
Commune fixed effect	YES	YES	YES	YES

6.2. Overconsumption Price Policy

From the DCC literature, the estimated price elasticity under nonlinear prices is a complex function of each block and switching point and the probabilities of consumption in any part of the budget constraint. This mathematical technicality might explain the differences in elasticities under UP and IBT. However, other factors are mentioned in the literature, such as climate issues, pro-conservation attitudes, and patterns in water consumption, according to the final use of water.

In our case, the characteristic of the tariff structure also plays an important role in price elasticity differences. Recall from the background section that the second block starts at a very high level of consumption, at least 40 m^3. Thus, an average household should increase their consumption around three times to reach this block, and this unlikely situation produces a tiny number of households consuming in the second block. Empirically speaking, a group of consumers behaves as if they face a UP tariff structure throughout the year, while a small group faces the increasing block structure during summer.

Table 7 presents the group analysis described in the methods section. This table shows elasticities according to groups of consumption levels indicating that consumers have seasonal behavior and act according to the tariff structure they face. In both cases, under UP or IBT, the consumers' reaction to price is inelastic, but families react more under IBT. In contrast, low-level consumption households respond to changes in price levels but not to tariff changes since, in summer months, they never face overconsumption prices. Their summer elasticity is low compared with the high-level consumption group.

We should expect summer consumption and higher prices to generate a positive correlation between prices and quantities, biasing the elasticity toward zero (or even positive). Notoriously, we observed this behavior only in the group with low consumption. Table 7 shows that for the low consumption group, unaffected by the change in tariff, the elasticity in the nonsummer is higher (more elastic) than in the summer (−0.299 vs. −0.071, respectively). Unlike the low-consumption group, the elasticity of demand for the high-consumption group increases significantly in the summer to −0.568. The higher consumption group is indeed affected by the change in tariff.

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Table 8
Summer Water Demand for High-Level Consumption Group

Group	Households	Summer consumption (m^3)	Nonsummer consumption (m^3)	Ratio summer/nonsummer consumption
Low consumption	16,673	5.46	4.83	1.13
High consumption	13,934	33.90	31.19	1.09

The results also show that the high-consumption group has a lower elasticity in the nonsummer months than the low-consumption group in the same months (−0.132 vs. −0.299, respectively).

Table 8 shows the average level of consumption per group by period. The main conclusion from these results is that the IBT structure significantly affects those individuals in the upper tail of consumption. Consumers in the first group reduce their elasticity from nonsummer to summer months and increase their consumption by 13%. Because of summer conditions, they will increase water use and have less capacity to constrain water use in this period. The second group also increased its summer consumption, but only by 8.7%, and contrary to the first group not affected by the new tariff, its elasticity increased significantly. The difference in consumption increase between the low and high consumption groups is around 34% (in comparison to the first group). Let us suppose, conservatively, that the high-consumption group would have behaved similarly to the low-consumption group; then they would increase their consumption by 13% (equivalent to an additional 1.37 m^3 on average per household).

7. Conclusion

The relevance of accurate price elasticity estimates under a nonlinear tariff structure, such as increasing block rate, is crucial in analyzing any tariff policy. This metric is an essential input in the evaluation of consumer effects of changes in price or tariff reforms, for example, the analysis of consumer welfare effects. This paper estimates the residential water demand and its price elasticity under systematic shifts between UP and increasing-block tariff structure. Unlike previous literature, our data set presents the advantage of evaluating consumption behavior as a "yearly- natural experiment." Each household faces an IBT during the summer months and a UP tariff the rest of the year; this situation occurs yearly.

We estimate different models according to the tariff structure faced by the consumer, IBT or UP. We also consider distinct treatments of the sample, splitting it between summer and nonsummer months and between low and high consumption levels. Under UP and IBT, the consumers' reaction to prices is inelastic, but households react more to prices under IBT. The utilization of IBT is gaining popularity worldwide because policymakers think this could help water conservation in the current context of high-water scarcity. From a policy perspective, our findings have two main implications. First, people do react to changes in tariffs. Second, a tariff reform design should consider consumers' heterogeneity. In our case, the IBT rate could have been designed better since the upper block kicks in when consumption exceeds 40 m^3/month, but the median summertime use is 13.1 m^3/month, and the mean is 15.9 m^3/month. Consequently, a group of water users acts as though they face a UP structure since their summertime usage is unlikely to take them into the upper block rate. There is also a group whose summertime usage either takes them into the upper block or puts them close to the kink point. Those users should undoubtedly be modeled as though they respond to the IBT structure. There may be an intermediate group of users where it is unclear whether they behave as though they face an IBT or a UP rate structure. Therefore, policymakers need to carefully define the tariff structure to reach a higher proportion of the population with the upper block.

Finally, our results differ from those showing that consumers do not respond to marginal price, indicating the opposite. This result highlights that the empirical evidence surrounding this debate is open and remains a point of disagreement. We are reaffirming the importance of not generalizing the results in this document.

Appendix A

Table A1 below summarizes the main characteristics of the articles related to our paper.

Table A1
Literature Estimating Residential Water Demand Under Different Tariff Structures

Authors	Goal	Data	Data aggregation	Compared periods	Estimation strategy	Observations
Hewitt and Hanemann (1995)	Estimation of residential water demand using the DCC model	June, July, and August	No	No	DCC and reduced-form IV	Price elasticity under the DCC model ranges from −1.57 to −1.63. Price parameters under IV are positive and statistically not significant
Olmstead et al. (2007)	Residential water demand under different tariff structures	1,082 households from 11 urban areas in USA and Canada, different rates according to cities	No	No	DCC and Regression models	Price elasticity, full sample: −0.33 Price elasticity, IBT: −0.5893 Price elasticity, UP: −0.3258
Olmstead (2009)	Residential water demand was estimated using reduced form and structural model	Data of 671 households in seven urban areas in USA and Canada, served by 10 water utilities (1998)	No	No	DCC and IV, and then Monte Carlo simulations to study the bias of both models	−0.29 under IV elasticity conditional on households remaining within their currently observed segment of the budget constraint −0.61
Grafton et al. (2011)	Estimation residential water demand. Controlling for different tariff structures	OECD household Survey on Environmental attitudes and behavior (2008)	NO	No	Regressions models	Possible bias due to self-reported data No information of price and tariff structure Price elasticity: −0.43
Sebri (2013)	Water demand under different tariff structures	Aggregated data of 21 Tunisian governorates over 21 years	Yes	No	DCC model	Price elasticity in a range of −0.62 and −0.74, depending on region
Baerenklau et al. (2014)	Residential water demand under different tariff structure	EMWD of southern California	No	The same sample but different periods	Regression models and DCC	Household under UP until April 2009, then IBR structure. Independent estimates according to rate UP elasticity: −0.76 DCC elasticity: −0.58
Szabó (2015)	Evaluate the welfare effects of free water, and provide an optimal price schedule derived from a social planner's problem	Low-income country (Africa)	No	No	DCC for estimating residential water demand	Average price elasticity of water demand estimation: −0.98

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Table A1
Continued

Authors	Goal	Data	Data aggregation	Compared periods	Estimation strategy	Observations
Clarke et al. (2017)	Water demand under combination of tariff structures: volumetric (per-unit, four-tiered IBR) and fixed (flat) charges	Panel data on water consumption at the household level. Tucson city	No	No	Stone-Geary Model	Mean and median of price elasticity in a range between −0.4 y and −0.1 depending on period
Klassert et al. (2018)	Residential water demand under IBT in Jordan	Household Expenditures & Income Survey. HEIS of Jordan. Five surveys from 2002 to 2013	No	Yes	DCC model	Average price elasticity between all years: −0.24
		Until 2011 IBT included linearly progressive. 2013 IBT				Price elasticity in 2013: in a range of 0 and −1.45, with an average of −0.26
Thrikawala et al. (2008)	Differences of two tariff structures on water demand	Primary data from a field survey, Kandy	No	No	OLS models	The results revealed that no substantial changes in residential water demand can be expected due to any of the price policy due to the current situation
Rosenberg (2010)	Apply a deductive model of residential water demand to simulate demand responses over many rate structures	Cross-sectional sample Amman, Jordan	No	No	Deductive model residential water demand model	Inelastic piper water demand responses for all rate structure at historically low prices. Piped water demand turns more elastic when prices rise above $0.50/m^3 (uniform rate shows the most elastic response)
Renzetti et al. (2015)	Using price elasticity to model annual aggregate water use changes in response to future changes. In major demand drivers	Demand Elasticities for each of the drivers. Elasticity values taken from case studies were similar to York Region's feature	Yes	No	Forecasting approach. Scenario-building approach	El documento proyecta variaciones en la demanda de agua tanto de uso residencial como no residencial
Smith and Al-Maskati (2007)	Investigates different water tariff structures & seeks to identify the factors affecting WDM (water demand management) through tariffs	Information on tariff structures in Bahrain and other countries (OECD and GCC - Gulf Cooperation Council)	Yes	No	Preliminary exploration of price elasticity of demand for water figures obtained from various countries	Recommendations for future research aimed at estimating price elasticities of demand in Bahrain

Appendix B: Theoretical and Econometric DCC Model

The conditional demand to a k consumption block is equal to the demand equation evaluated in the marginal price for the corresponding block (p_k), and the household income plus the compensation or virtual subsidy (d_k) (Nordin, 1976) as:

$$d_k = \begin{cases} 0 & si\ k = 1, \\ \sum_{j=1}^{k-1} (p_{j+1} - p_j)\, w_k & si\ k > 1. \end{cases}$$

The conditional demand under the log–log functional form is:

$$w(p_k, y + d_k) = \exp(Z\delta)\, {p_k}^{\alpha} (y + d_k)^{\gamma} \tag{B1}$$

The unconditional demand is a function of all consumption blocks and kink points. For instance, the unconditional demand for $k = 2$ is:

$$\ln w = \begin{cases} \ln w_1^* & si\ \ln w_1^* < \ln w_1 \\ \ln w_1 & si\ \ln w_1 < \ln w_1^*\ y\ \ln w_1 > \ln w_2^* \\ \ln w_2^* & si\ \ln w_2^* > \ln w_1 \end{cases} \tag{B2}$$

w represents the observed water consumption, $w_k^* = w_k^*(Z, p_k, (y + d_k); \alpha, \gamma, \delta)$ is the optimum water consumption in the k block, and w_1 is the kink point. Equation B2 is unknown to the researcher therefore, the econometric modeling includes two error terms (Hewitt & Hanemann, 1995; Moffitt, 1986): η, which captures the heterogeneity among households, which is not captured by the sociodemographic and climate variables Z; and ε, which represents characteristics that are not observed by either the researcher or the households (Olmstead et al., 2007). η and ε are iid normally distributed, with means equal to zero and variances σ_η^2 and σ_ε^2. The unconditional demand is equal to:

$$\ln w = \begin{cases} \ln w_1^* + \eta + \varepsilon & si\ -\infty < \eta < \ln w_1 - \ln w_1^* \\ \ln w_1 + \varepsilon & si\ \ln w_1 - \ln w_1^* < \eta < \ln w_1 - \ln w_2^* \\ \ln w_2^* + \eta + \varepsilon & si\ \ln w_1 - \ln w_2^* < \eta < \infty \end{cases} \tag{B3}$$

The likelihood function related to Equation B3 is equal to:

$$\ln L = \sum \ln \left[\begin{aligned} & \left(\frac{1}{\sqrt{2\pi}} \frac{\exp(-{s_1^*}^2/2)}{\sigma_v} (\Phi(r_1^*)) \right) \\ & + \left(\frac{1}{\sqrt{2\pi}} \frac{\exp(-{s_2^*}^2/2)}{\sigma_v} (1 - \Phi(r_1^*)) \right) \\ & + \left(\frac{1}{\sqrt{2\pi}} \frac{\exp(-{u_1^*}^2/2)}{\sigma_\varepsilon} (\Phi(t_2^*) - \Phi(t_1^*)) \right) \end{aligned} \right]$$

where:

$$\rho = \mathrm{corr}(\varepsilon + \eta, \eta); \qquad v = \eta + \varepsilon$$

$$s_k^* = (\ln w_i - \ln w_k^*(\cdot))/\sigma_v; \quad u_k^* = (\ln w_i - \ln w_k)/\sigma_\varepsilon$$

$$t_k^* = (\ln w_1 - \ln w_k^*(\cdot))/\sigma_\eta; \quad r_k^* = (t_k^* - \rho s_k^*)/\sqrt{1 - \rho^2}$$

Given that η and ε are normally distributed, $\exp(\eta)$ and $\exp(\varepsilon)$ are distributed lognormal. The expected consumption is given by (two tiers):

$$E(W) = e^{\sigma_\eta^2/2} e^{\sigma_\varepsilon^2/2} \left(w_1^* (p_1, y + d_1) * \pi_1^* + w_2^* (p_2, y + d_2) * \pi_2^* \right) + e^{\sigma_\varepsilon^2/2} w_1 * \lambda_1^*$$

With

$$\pi_1^* = \Phi\left(\frac{\ln(w_1/w_1^*)}{\sigma_\eta} - \sigma_\eta \right)$$

$$\pi_2^* = 1 - \Phi\left(\frac{\ln(w_1/w_2^*)}{\sigma_\eta} - \sigma_\eta \right)$$

$$\lambda_1^* = \Phi\left(\frac{\ln(w_1/w_2^*)}{\sigma_\eta} \right) - \Phi\left(\frac{\ln(w_1/w_1^*)}{\sigma_\eta} \right)$$

Olmstead et al. (2007) developed an analytical expression for price elasticity as the change in the expected value after a change in a proportion θ in the price vector, given by:

$$\frac{\partial E(W)}{\partial \theta} \frac{1}{E(W)} = \left(\begin{array}{l} \alpha\left(w_1^* \psi_1 + w_2^* \psi_2 + w_1 (\chi_1 - \chi_2)\right) \\ + \gamma\left(d_2 \left(\frac{w_2^*}{y + d_2} \right) \left(\psi_2 - \left(\frac{w_1}{w_2^*} \right) \chi_2 \right) \right) \end{array} \right) \Big/ \Omega$$

With

$$\psi_1 = \pi_1^* - \frac{1}{\sigma_\eta} \phi\left(\frac{\ln(w_1/w_1^*)}{\sigma_\eta} - \sigma_\eta \right)$$

$$\psi_2 = \pi_2^* + \frac{1}{\sigma_\eta} \phi\left(\frac{\ln(w_1/w_2^*)}{\sigma_\eta} - \sigma_\eta \right)$$

$$\chi_1 = \frac{1}{\sigma_\eta * e^{\sigma_\eta^2/2}} \phi\left(\frac{\ln(w_1/w_1^*)}{\sigma_\eta} \right)$$

$$\chi_2 = \frac{1}{\sigma_\eta * e^{\sigma_\eta^2/2}} \phi\left(\frac{\ln(w_1/w_2^*)}{\sigma_\eta} \right)$$

$$\Omega = w_1^* (p_1, y + d_1) * \pi_1^* + w_2^* (p_2, y + d_2) * \pi_2^* + e^{-\sigma_\varepsilon^2/2} w_1 * \lambda_1$$

Data Availability Statement

The data used in this research was supplied under a confidentiality agreement signed with a private water utility of the Region under study, and are not accessible to the public or research community. We can make this data available by signing a confidentiality agreement. All the procedures carried out in this research were done using RSTUDIO (v3.6.2; R Core Team, 2021) and STATA (StataCorp, 2015). The estimation processes collected in this research are available in Chovar Vera et al. (2023).

Acknowledgments
This study was funded by the ANID PIA/BASAL FB0002 (Center of Applied Ecology and Sustainability, CAPES, Chile), the ANID/FONDAP/15110009 (Center for Climate and Resilience Research, CR2), and the ANID/FONDAP/15130015 (Water Research Center for Agriculture and Mining, CRHIAM). We are grateful to anonymous referees for their comments and suggestions.

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